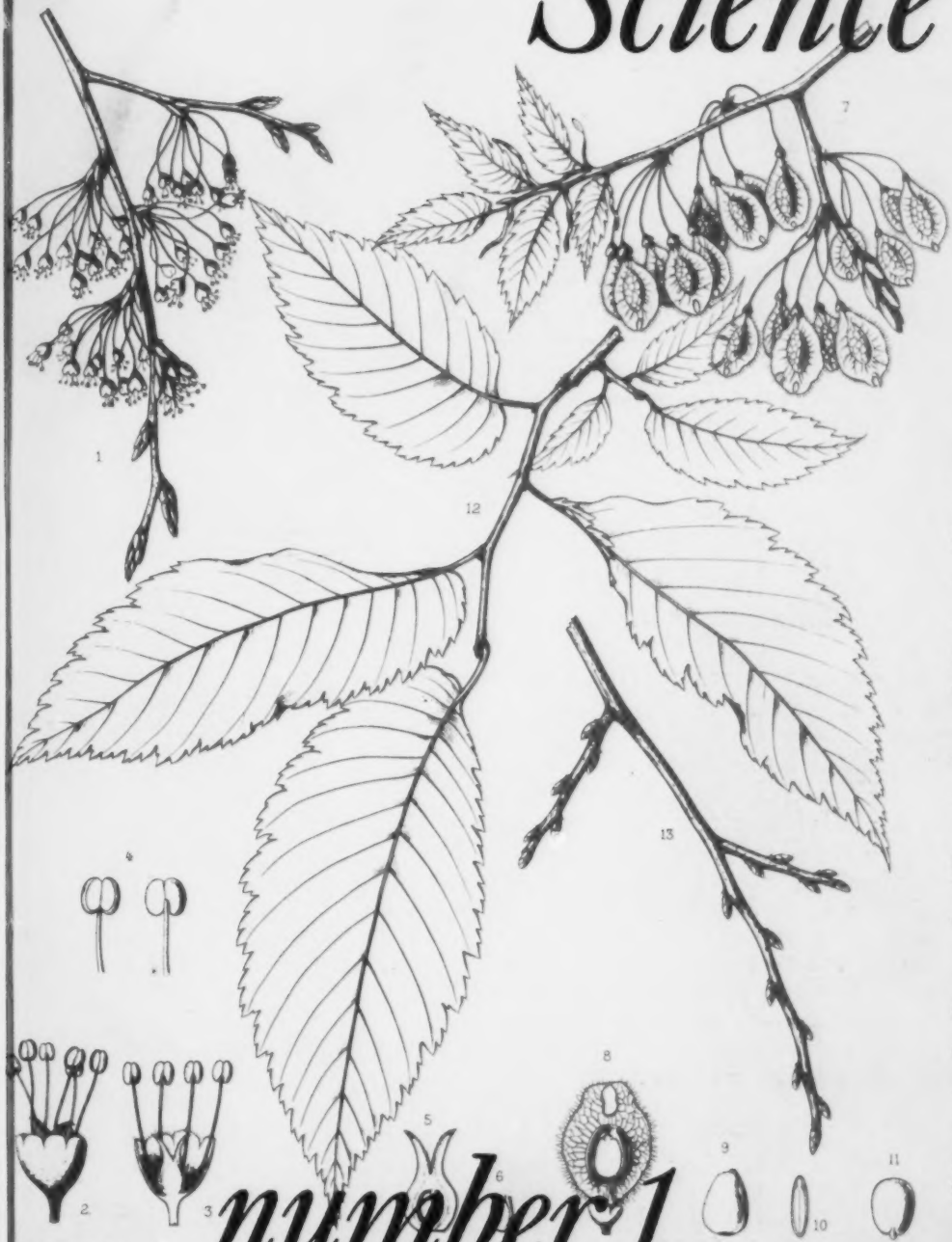
FOREST Science



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Windy Camp — An etching by George J. Young.

Forest Science: A Quarterly Journal of Research and Technical Progress

BY

E. L. DEMMON

THIS first quarterly issue of FOREST SCIENCE represents a landmark in scientific forestry publications in this country. Primarily intended to report the results of original investigations, it is being published by the Society of American Foresters with the cooperation of forestry research and educational institutions. The U. S. Forest Service and the School of Natural Resources of the University of Michigan have been particularly active in arranging for its appearance.

The first scientific forestry journal published in the United States was *Forestry Quarterly*, which began in October, 1902 at the New York State College of Forestry at Cornell University. One of the objects of the journal was "to offer an organ for the publication of technical papers of interest to professional foresters in America."

Although the Society of American Foresters was organized in 1900, its first technical journal did not appear until May, 1905, when it began publishing the *Proceedings of The Society of American Foresters*, primarily as an outlet for recording the papers read at Society meetings. The *Forestry Quarterly* and the *Proceedings* were published separately until January, 1917, when they joined forces and were amalgamated into the present *Journal of Forestry*, published by the Society of American Foresters.

Since 1917 the *Journal of Forestry* has been the only American journal devoted primarily to the technical field of forestry in this country. It has carried articles on all phases of forestry, and has printed many of the results of scientific investigations. Very few of these research articles, however, have exceeded 6 pages or 6000 words in length. In addition to this limitation on length, the *Journal of Forestry* cannot be expected to publish long articles, highly technical articles, or those dealing with research methodology which are of interest only to a segment of its readers. Several different studies of reader interest in the *Journal*, the latest by Editor Arthur B. Meyer (51:361-63, May 1953) indicate that a majority of *Journal* readers prefer fewer articles of a highly technical nature. A. C. Worrell of the University of Georgia, taking note of this, proposed a regional forestry journal for the South (Jour. For. 51:512-13, July 1953).

Formerly, the U. S. Forest Service used the *Journal of Agricultural Research*, published by the U. S. Department of Agriculture, for articles on the results of basic research, but publication of this journal was

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suspended in 1947. Since then, the federal forest experiment stations have issued many scientific papers as mimeographed or processed releases.

There are, of course, several journals relating to allied technical fields that accept articles on forestry subjects, including journals specializing in botany, ecology, entomology, pathology, economics, photogrammetry, soil science, and forest range management.

In recent years there has been a great expansion in forest research activities in the United States, and in 1953 the number of workers in this field exceeded 1400, with expenditures of $45,000,000, as reported by Kaufert in the *Journal of Forestry* (53:49, January 1955). Many of these research men have felt the need for another technical journal in the field of forestry. FOREST SCIENCE is aimed to meet this need.

Several specific proposals have been made for the initiation of such a journal as FOREST SCIENCE, and the matter has been discussed at the last four meetings of the Society's Division of Education. One of the leading proponents of the idea has been Professor Stephen H. Spurr, of the University of Michigan. At the Society meeting in Biloxi, Miss., in December 1951, he offered a motion placing the Division of Education on record as favoring the exploration of this subject. Following its unanimous acceptance, the Division Chairman appointed a committee to follow up on the matter, consisting of Earl L. Stone, Jr., of Cornell University, R. W. Dingle of the University of Missouri, and Spurr as chairman. In August 1952 this committee circularized many schools and institutions interested in forest research, and from the approximately 360 individuals who expressed views on the subject of a new journal, only 19 percent felt that it was not needed.

Spurr also kept the matter alive by contributions to the *Journal of Forestry* (50: 397, May 1952, and 50:565, July 1952), and by presenting the subject to the Society Council at its Montreal meeting in December 1952 (51:51, January 1953). H committee also submitted a report to th Division of Education at the annual Societ meeting at Colorado Springs, Colorado, i September 1953.

In order to commence publication of new technical forestry journal, with limited circulation at first, it seemed essen tial that the project be underwritten finan cially until subscriptions could carry it. Th Council of the Society of American For esters did not feel that they could use the limited resources for this purpose, but their summer meeting in Ann Arbor, Mich igan, in June 1954, they were given understand that the project had been o fered a grant of $2,000 by the Horace H Rackham School of Graduate Studies the University of Michigan to help get started. With that assurance, the Counc gave its support by a promise to contribu certain business services, such as solicitin subscriptions, maintaining a mailing list subscribers, and handling funds, but with out financial obligation (Jour. For. 52:624 25, August 1954).

With this initial issue, FOREST SCIENC is now launched on what should be the b ginning of a long and distinguished caree in the field of technical forestry publication It represents a cooperative venture betwe three organizations — the University Michigan, the U. S. Forest Service, and t Society of American Foresters—with a re resentative of each on the editorial boar Every effort will be made to avoid compet tion with existing journals. In fact, clo correlation will be maintained between t editors of the *Journal of Forestry* and FO EST SCIENCE in placement of articles whe they are best suited.

The pages of FOREST SCIENCE will open to all qualified contributors. Prefe ence will be given to papers devoted to t presentation and discussion of the results original research. Reviews of both foreig and domestic books will be carried. T editors have tried to achieve a format whi

will be both economical, attractive, and in harmony with the scholarly nature of the periodical. The typographic design is by George Lenox, Art Director of the University of Michigan Press. Subscription exchanges with foreign organizations will be handled by the University of Michigan library which will purchase FOREST SCIENCE subscriptions for that purpose.

To assure success for the new journal, the wholehearted support of organizations and individuals engaged in, or vitally interested in, the field of forest research will be needed. I am sure that many foresters in research, education, and practice will recognize its value for reference purposes, and will want to maintain a complete file.

As an alumnus of the University of Michigan, and as a long-time member of the U. S. Forest Service and of the Society of American Foresters, I heartily commend this new enterprise in the field of forestry journalism and urge widespread support for it.

Grundner and Schwappach Massentafeln (Volume Tables).

10th Edition. Edited by R. Schober. 1952. Paul Parey, Berlin and Hamburg. 216 pp. DM 14.80 ($3.50).

REVIEW by Stephen H. Spurr
University of Michigan

The tenth edition of these standard volume tables for Germany has much of interest to American foresters. It serves to indicate the types of volume tables that have stood the test of time over half a century in a country where mensurational studies have been exhaustive.

Eleven species are covered by tables based on the measurement of 71,191 trees. The tables for Scotch pine based on 17,059 trees will serve to show the information presented. Their most striking feature is the absence of form class measurements which have been tried at length in Germany over many years and which gradually have fallen into disuse. Instead, the volume tables for Scotch pine are presented first for trees up to 80 years in age and second for older trees. This division, coupled with the conventional height and d.b.h. breakdown, seems adequate for volume estimation.

Separate volume tables give estimates for merchantable cubic and total cubic volumes. These are followed by (1) a table giving the amount of brushwood in tops as a percent of the merchantable cubic volume; (2) a cordwood table giving the cubic measure of 100 sticks; (3) a height-curve table showing for each region in Germany the relationship between diameter and height as related to the diameter and height of the average stem; (4) taper tables for trees of various heights; (5) bark thickness tables for various heights above the ground on trees of various diameter classes; and (6) a log table presenting for each tree height the characteristics of logs that would be cut from the tree.

A major objective of the new edition, as stated in the preface, was to give due emphasis to the increasingly important development of evaluating log grades in the standing trees. Auxiliary tables have been added to permit the estimation of the wood-quality grade of standing trees, and especially the quality and diameters of the lower logs.

American foresters may well profit by this example of the systemizing and reduction of mensurational data. Even the tables themselves may be useful. For example, the reviewer found in his book *Forest Inventory* that the Grundner - Swappach spruce volume table fitted an American spruce sample better than some American tables.

An Economic Approach To Multiple Use

BY

G. ROBINSON GREGORY

IN almost any discussion of wildland problems one will hear "multiple use" cited as a guiding managerial principle. At times one nearly gets the impression that "multiple use" is a panacea for all problems of public land administration, and an important guide to private property management as well. There has been remarkably little difficulty in gaining general acceptance of the multiple-use idea—the difficulties arise in application. Most people readily concede, for example, that timber production is not the sole function of public forest land —that forage, water, wildlife, and recreation should all be considered in management decisions. But how should the forest administrator decide between these many uses, and (even more difficult) how much managerial effort and cash should be directed toward each use? As an idea, multiple use has met with almost universal acceptance; as a working tool of management, it has had far less success.

This paper has three objectives:

1. To present an economic analysis of the multiple use concept.
2. To review two current approaches to multiple use often presented as being divergent, and show how both are amenable to the suggested analytical approach.
3. To discuss two of the more important problems that must be solved if the suggested approach is to be given empirical content.

An Economic Framework

Broadly speaking, multiple use of land means using a particular land area to produce more than one good or service. The production of more than one product from the same plant or through use of the same process may be treated under joint-production theory. Wheat and straw, or beef and hides, are frequent text-book examples of joint production. It is believed that this theory can be applied almost directly to the multiple-use problem. Because it lends itself to graphic treatment, the two-product case will be considered first; the generalized multi-product problem will follow.

Suppose a land manager has an area suited to the production of timber and forage. Assuming that the techniques for producing both products are established and available to the land manager, his problem is simply that of deciding whether to produce timber, forage, or some particular combination of the two from the given area. The land area may thus be taken as the fixed factor.

If a graph is constructed with quantity of timber scaled along one axis and quantity of forage along the other, any combination of these two products can be represented by a single point. In Fig. 1, for example, *A*

The author is George Willis Pack Assistant Professor of Resource Economics, School of Natural Resources, University of Michigan.

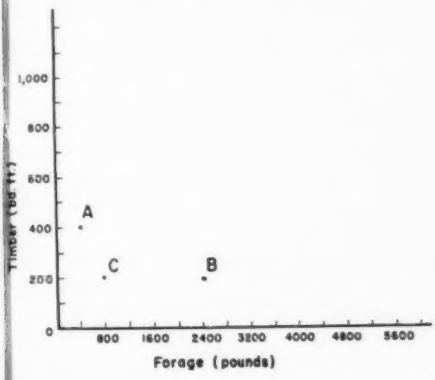

Fig. 1. Any possible output combination of two products can be plotted on a diagram of this type.

represents a combination of 400 bd. ft. of timber and 400 pounds of forage; *B* a combination of 200 bd. ft. of timber and 2400 pounds of forage. If no management activities were undertaken on the area the combination *C* might result.

But if there is a management problem, it can be assumed that something is to be done, hence costs will be incurred. To bring these costs into the picture necessitates use of a third dimension. If the forage and timber scales are plotted on a horizontal plane, costs can be represented by the height above this plane. In Fig. 2 a few of the infinite number of possible timber-forage combinations are shown, with the height of the column indicating production costs. If *C* is again the combination achieved without managerial activity, then costs would necessarily rise in any direction from this point. Only the increased yields, however, are economically significant.

By connecting all those columns of equal height (in effect, by constructing a contour map of Fig. 2) a set of curves similar to the solid lines in Fig. 3 will be generated. Each curve represents all the combinations of timber and forage that can be produced at some given cost, hence are called "iso-cost" curves. While an infinite

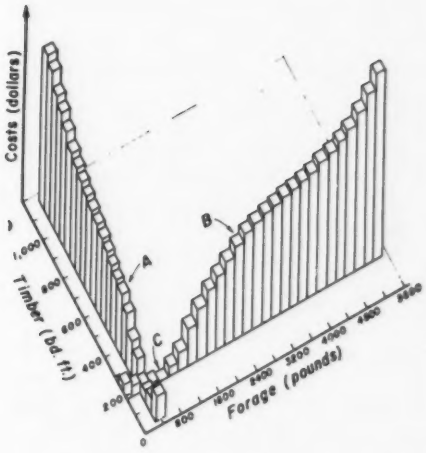

Fig. 2. Costs may be indicated by the height of a column above a plane.

number of these curves could be drawn, only a few are illustrated. The shape of the individual curves, as well as the pattern of the entire curve family, would be expected to differ for every area. An illustration of this will be given later.

So far only production costs have been treated. Management aims, however, to maximize net revenue, and to achieve this objective revenues must be introduced. The approach is directly analagous to that taken with costs, though less complicated. If any point on the timber axis is selected, conversion to dollar values can be readily accomplished by multiplying the volume by the unit market price. For example, if the market price of stumpage were $20 per M.B.M., 400 bd. ft. would be worth $8 (point *t* in Fig. 3). The quantity of forage worth an identical amount at its current market price can be similarly calculated and located on the forage scale. In the present example a forage price of $6.67 per ton was assumed. Eight dollars worth of forage would therefore be 2400 lbs. (point *f*). By connecting these two points all possible combinations of timber and forage producing $8 in revenue will be identi-

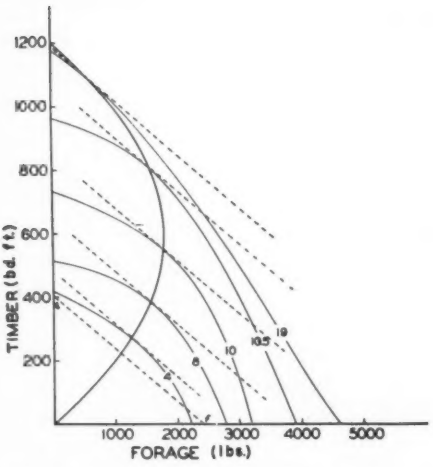

Fig. 3. Iso-cost curves (———) identify all product combinations that can be produced at equal cost. Iso-revenue curves identify all product combinations that will yield equal revenues. The expansion path, through points of tangency,, locate a series of product combinations that should be considered by the land manager.

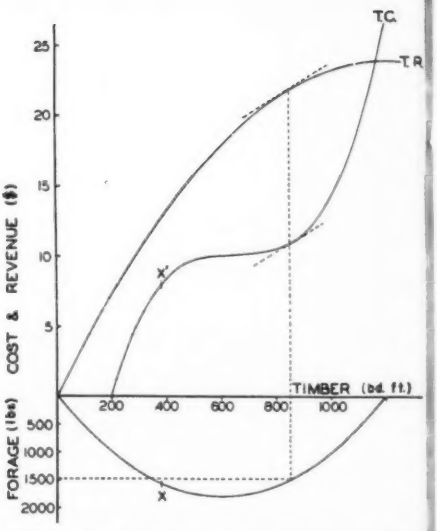

Fig. 4. Solution of the two-product case. Total cost (TC) *and total revenue* (TR) *curves in upper part of figure are directly related to the product combinations identified by the expansion path in the figure's lower portion.*

fied, for all will necessarily lie on this line.[1] Once this line has been located the entire family of iso-revenue curves is established, for all such lines will be parallel.

With both iso-cost and iso-revenue curves determined, the task of isolating the most desirable combination of products can be narrowed a great deal. The manager will of necessity operate at some point on an iso-cost curve, since these curves include all possible product combinations.[2] For any given production cost he will want to assure the return of the highest possible revenue. The manager can be visualized, therefore, as moving *along* an iso-cost curve until the highest revenue is obtained. This will be achieved only when the point of tangency between the iso-cost and iso-revenue curves is reached, for at no other point can he realize so high a revenue with the chosen expenditure. Hence a line connecting these points of tangency (the "expansion path") will delineate all those combinations of timber and forage that the land manager should consider.

The final step consists of identifying which of the combinations on the expansion path will maximize net revenues from the area. The solution is illustrated in Figure 4. The lower part of the diagram consists of the expansion path that was previously constructed.[3] The upper half reproduces the traditional curves of economic theory—total cost and total revenue. The only difference between this upper set of curves and those developed in usual profit maximiza-

[1]This is true for timber and forage, since no area being analyzed in this fashion would be large enough to produce quantities that might significantly affect the price of either product. With other products this might not be true. In this latter case the iso-revenue lines would be curved, and their location would necessitate knowledge of the product demand functions.

[2]Bear in mind that only a few of the iso-cost curves are illustrated in Fig. 3.

[3]The expansion path, together with the two axes, has simply been rotated 90 degrees to the right.

tion theory lies in their applicability to a production combination rather than to a single product. The total cost and total revenue curves are derived from, hence directly related to, the expansion path in the lower portion—they are functions of *both* product outputs. The cost of producing (for example) the product combination X in Fig. 4 (380 bd. ft. of lumber and 1550 lbs. of forage) can be read directly from the total cost curve, and is identified by X' (8 dollars). Since the objective is to maximize returns from the area, the proper combination of timber and forage will be that one which achieves the greatest positive difference between total cost and total revenue. This difference will be maximized where the slopes of the total cost and total revenue curves are equal—where marginal cost equals marginal revenue — and is shown in Fig. 4 as being approximately 850 bd. ft. of timber and 1500 pounds of forage.[4]

Because geometry is limited to portrayal of three dimensions the development has thus far been restricted to multiple use involving only two products. Yet in practice the problem is seldom so restricted. Multiple use of public lands frequently involves consideration of timber, forage, wildlife, water, recreation, and other goods or services. To extend the approach to these more complex (but more real) problems, mathematics must be substituted for geometry. The same two-product case will be used, and changes necessitated by additional products indicated as the development proceeds.

The technical production possibilities depicted in Figure 1 can be expressed mathematically by a set of production functions. If more than one product is to be produced from the given area, then it can be assumed that at some point the output of one product will influence the output of another. Hence, in addition to the input variables commonly associated with the production function for each product, the output of each of the other products must also be entered as a variable. In the timber and forage case we might have, for example:

$$Q_t = f(x_1, x_2, x_3 \ldots x_n; Q_f)$$

$$Q_f = f(x_1, x_2, x_3, \ldots x_n; Q_t)$$

as the generalized production functions, with Q_t and Q_f representing the outputs of timber and forage, and $x_1, x_2, x_3 \ldots x_n$ the inputs of variable services required. A separate production function will be required for each product, so there will be as many equations as products being considered. No entry need be made for the land, since this is taken as the fixed factor.

The steps through which costs and revenues were introduced (illustrated by Figures 2 and 3) seem desirable graphically but may be bypassed in the mathematical solution. Total cost of producing any particular combination can be derived as a summation of the various input costs and ultimately expressed as a function of the output of the several products, just as indicated in the upper part of Figure 4. This equation[5] can be expressed generally as $TC = f(Q_t, Q_f)$. Additional products will necessitate additional output variables, but no further complication is introduced at this point by increasing the number of products.

Similarly, the total revenue curve can be translated into a function of the output of the two products.

In many multiple product cases the possible combinations will be limited by technical considerations. It seems probable that in most situations the expansion path could be determined without resort to a complex

[4]It will occur to any forester that the possibility of growing this particular combination is somewhat remote. It was decided in this case, however, to sacrifice reality for simplicty of illustration.

[5]From this same equation the family of isocost curves may be derived. Considerable insight is gained by a careful analysis of these cost relationships, but since it is not necessary for the final solution, the full development is not presented here.

production function analysis. In any event, once the expansion path has been determined, the product combinations can be treated as a single new product, and total revenue and total cost curves derived. The total revenue curves illustrated in Fig. 4, for example, can be expressed by the equation

$$TR = 4X - 0.167X^2$$

Similarly, the total cost curve is described by the expression

$$TC = -20 + 13.75X - 2.083X^2 + 0.105X^3$$

In both equations, while the product combination (X) is identified by the timber part of the output (in hundreds of bd. ft.) it is nevertheless a combined variable. To illustrate: the total revenue that can be realized from the combination of 500 bd. ft. of timber and 1750 lbs. of forage (on the expansion path) can be determined by substituting 5 for X in the total revenue equation and will be

$$\text{TR} = 4(5) - 0.167\ (25) = \$15.83$$

This same result can be obtained by adding the revenues from each product:

500 bd. ft. of timber at \$20 per M =	\$10.00
1750 lbs. of forage at \$6.67 per ton =	\$5.83
	\$15.83

From the total cost equation it is seen (again by substituting 5 for X) that the total cost of producing this same combination will be \$9.80.

$$TC = -20 + 13.75(5) - 2.083(25) + 0.105(125) = \$9.80$$

Where product combinations are highly variable, it will usually be preferable to express both total cost and total revenue as joint functions of the products, rather than by using a combination variable. Derivation of such functions can probably best be accomplished through the production function approach previously outlined.

In the graphic illustration, the product combination maximizing returns was determined by establishing the point at which the total cost and total revenue curves have identical slopes. This is simply another way of expressing the necessary equality of marginal cost and marginal revenue, since the slope of these curves represents the change in cost (or revenue) associated with a corresponding change in output. Mathematically, marginal cost and revenue may be determined by taking the first derivative of the total functions with respect to output.

Since equality of marginal cost and marginal revenue is a necessary condition for profit maximizing, the two marginal expressions can be equated and the profit-maximizing output determined directly.

From the total cost and total revenue equations previously developed, for example, the following two marginal expressions can be derived through differentiation:

$$MC = \frac{dTC}{dX} = 13.75 - 4.166X + 0.315X^2$$

$$MR = \frac{dTR}{dX} = 4 - 0.334X$$

If marginal cost is to equal marginal revenue, then

$$13.75 - 4.166X + 0.315X^2 = 4 - 0.334X$$

which simplifies to

$$0.315X^2 - 3.832X + 9.75 = 0$$

Solving this by means of the quadratic formula, it is seen that the desired output

[6]Actually, since a quadratic expression was used, there will be two roots which satisfy the equation, and in this case both roots are real. One needs only to subtract costs from revenue, however, to identify which is the profit maximizing combination. In this instance the second root is 3.62, or 362 bd. ft. of timber. From the equation, TC at this output is \$7.46, and TR = \$12.29. Net revenue is therefore 12.29 — 7.46 = \$4.83. A similar calculation with the other root (854 bd. ft.) yields a net revenue of 21.98 — 10.91 = \$11.07.

combination consists of 854 bd. ft. of timber and the associated 1480 lbs. of forage.[6]

Had joint cost and revenue expressions been derived (as is necessary for a general solution) the marginal functions would be determined by taking partial derivatives of the total functions with respect to each of the products. If, for example, total cost is represented by the generalized expression

$$TC = f\,(Q_t, Q_f)$$

Then the two marginal cost relationships are simply

$$MC = \frac{\partial TC}{\partial Q_t}$$

and

$$MC = \frac{\partial TC}{\partial Q_f}$$

The resulting marginal cost and revenue expression would next be equated, just as in the illustrative case, but now would form an equation system in terms of product outputs. Since the number of unknown product outputs would be equaled by the number of equations, this system could be solved simultaneously to yield the set of product outputs that would maximize net return from the land area under the given cost and revenue situation.

One observation should perhaps be made: throughout the development there has been an implicit assumption of instantaneous production. This assumption is of course unrealistic and was made to avoid introduction of discounting formulas, etc. To relax this assumption requires only that all anticipated costs and revenues be discounted to a common point in time.

Current Approaches

Having presented an economic framework for analyzing multiple-use problems the question of how it fits in with current interpretations of the concept might well be raised. Two such interpretations may be distinguished on the basis of area applicability. One group, perhaps best exemplified by G. A. Pearson,[7] would apply multiple use to large areas but maintains that managerial subdivisions of the total area should be devoted to specialized uses. Any specific acre, therefore, would be put to a single use—the use to which it was eminently suited—though the area as a whole might be producing a variety of goods and services. The second group, exemplified by Dana[8] and McArdle,[9] would hold that multiple use may require the production of several goods and services from the same acre.

Logically, the Pearson approach requires the land manager to settle upon a "primary" use for each subdivision of the total area. "Secondary" uses would be tolerated only as long as they do not interfere with the primary use. If, for example, it had been decided that a particular area was best suited to timber production, forage production might also be tolerated, but never to the point where income from timber was reduced.

In contrast, the Dana-McArdle approach would hold that the major objective in managing this same tract was to maximize returns from the area, and would further maintain that the combination of forage and timber which would achieve this maximization might entail some sacrifice of timber output.

Admittedly, the contrast between these two approaches has here been emphasized. Under many—perhaps most—current situations both approaches would yield practically the same result. Yet in an economy characterized by an ever-expanding consumption of natural resources it might be expected that differences could increase. Conflicts between land uses are unusual when there is an abundance of land—the

[7]G. A. Pearson. 1944. Multiple use in forestry. J. For. 42: 243-249.

[8]S. T. Dana. 1943. Multiple use, biology, and economics. (Editorial) J. For. 41: 625-626.

[9]Richard E. McArdle. 1953. Multiple use —multiple benefits. J. For. 51: 323-325.

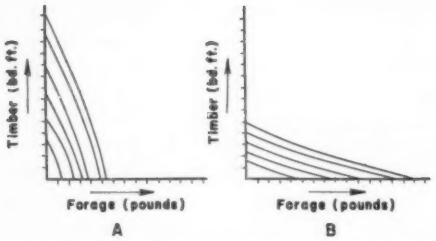

Fig. 5. Possible iso-cost patterns for two very different kinds of areas. Area A *would favor timber production, Area* B *forage production.*

real problems arise when expansion of one use means curtailment of another, and land in the United States is being used ever more intensively.

To compare these two approaches, suppose that the land manager is working with areas, each of which is definitely suited to the production of a single product. Possible iso-cost patterns for two very distinct areas—one eminently suited to timber production, the other to forage production—are illustrated in Figure 5. If the scales on the two diagrams are identical, and if the product price relationships are the same as those used previously, the expansion path in Figure 5A would coincide with the timber axis, and in 5B with the forage axis. This indicates simply that under such conditions any combination of timber and forage will be less profitable than would the single product for which the area is best suited. In a situation of this type, therefore, the Pearson approach would be entirely justified. It is obvious, however, that it represents only a special case.

If the situation is not as depicted in Figure 5—if instead it resembles more closely that illustrated by Figure 3 — then the Dana-McArdle approach is necessary if maximum returns are to be achieved. It appears, therefore, that the Pearson approach is not in fundamental conflict with that of the Dana-McArdle school. It is simply a special case in the general problem.

Figure 5 makes it clear that it is entirely possible for one product to be favored exclusively under one price relationship, but not under another. Similarly, it is to be expected that the optimum product combination will alter (the expansion path will shift) as either cost or revenue relationships change. Furthermore, on some areas it might well happen that two uses that were complementary at one intensity of management might be competitive at another.

Quantification Problems

The reader will undoubtedly have noted that only dollar values were used in developing the framework. Yet quantification in monetary terms is by no means a prerequisite, although some common denominator must exist before value comparisons can be made objectively. So long as the appropriate costs and returns are entered in the analysis, this approach has equally valid application to public or private problems. In the former, one would expect social costs and social returns to be used for the various products — in application to private areas it is probable that only those costs and returns affecting the owner would be entered. Even so, it is obvious that only a framework has been developed. Putting meat on the skeleton will involve a great deal of research in several areas, at least two of which warrant emphasis.

The first concerns all those products which are not usually valued by market transactions. The major stumbling block here is the quantification of non-market-determined values in terms that permit objective comparisons to be drawn. There are many[10] who feel that no attempt should be made to place dollar values on wildlife, scenic views, and the like, yet the troublesome fact persists that in an economy such as ours, things valued in dollar terms often have a distinct competitive advantage. A rocky, lonesome coast line may be "priceless" to the lover of seascapes, but it

[10]For example, note Robert Marshall's quotation, appearing in Dana's article cited in footnote 8.

has little likelihood of keeping its beauty if oil is known to lie beneath the rocks.

The problems inherent in quantifying non-market-determined values lie beyond the scope of this paper, but it seems appropriate to observe that the technique developed in the iso-cost diagram may contribute to determining some of these values. To illustrate: suppose a product with a readily measurable value (such as timber) is placed on one scale, and on the other some less easily valued product (perhaps wildlife). One may still construct iso-cost curves, since these depend upon a purely physical base coupled with determinable *cost* data. The difficulty would seem to lie with constructing iso-revenue lines, for their slope is the very item in question.

But suppose one has an area in which it is believed that the balance between wildlife and timber is approximately correct. The iso-cost curves can be plotted as above and the present point of operation located on one of these curves. If it is assumed that the present balance is correct, then a line tangent to the iso-cost curve at the present point of operation permits one to identify the "value" of the product. The slope of this tangent will be equal to the ratio of the two values, one of which (timber) is readily quantifiable. For example, if the slope were 45 degrees, and 25 dollars' worth of timber were intercepted on the timber scale, then the quantity of wildlife intercepted on its scale would also be worth 25 dollars. This is, of course, simply an extension of the opportunity-cost concept and does not presume to determine the intrinsic "value" of wildlife which may be "worth" more or less to any single individual, just as a painting or a pair of shoes may be worth more or less than its purchase price to different people. It does, however, identify the value imputed to wildlife by the administrative decisions governing management of the particular tract. *It is the only economic value that wildlife can possess if one considers the balance between the two products to be correct.*

The second area requiring much research concerns determination of the returns to various intensities of management for timber, water, forage, and all the other products of wild land. "Cost and returns" studies made in forestry are steps in the right direction, but these steps must be lengthened a great deal. Isolated case studies will not suffice. It is not enough to know that "forest management pays" or that specific silvicultural practices will pay their way. We need to be able to give far better answers to the question: How much forest management pays most? This necessitates input-output analysis of a far higher order than that undertaken to date. The need for such study seems obvious.

Conclusion

In conclusion, it should be stated that, with the possible exception of the technique illustrated in Figure 4, the approach to multiple use which has been presented involves no methodology that might be considered new by a production economist. It is believed, however, that multiple land use has not commonly been recognized as a problem of joint production, and that this approach will be new to most of those working in the field of wildland management research. Furthermore, the approach seems to resolve in an objective fashion some of the confusion attending the multiple-use concept, and it may offer a start toward placing a value on those products some individuals wish to regard as "intangibles."

Spacing Tests in a Douglas-Fir Plantation

BY

KENNETH R. EVERSOLE

WHAT is the best spacing for Douglas-fir in plantations? How does spacing affect stand development and the growth, form, and quality of individual trees? These important questions have been the subject of study since 1925 at the Wind River Experimental Forest near Carson, Washington. Here, plantations were established to test spacings ranging from 4 x 4 feet up to 12 x 12 feet. Results from these various spacing tests are discussed in this report.

Some 137,895 acres of plantations have already been established in the Pacific Northwest (Oregon and Washington) on the national forests alone. About 14,000 acres were planted in 1954. A sizable investment is represented since planting costs now average about $23 per acre on the national forests. Whether the standard 8 x 8 foot spacing gives the best return on the investment has been the subject of debate among foresters in the Douglas-fir region for many years. One faction argues for closer spacing. This group says close spacing should be used to shade out lower branches and ground cover. The defenders of wide spacing say that close spacing entails prohibitive planting costs and results in snow break and reduced growth of the crop trees. These arguments are of practical importance. The forest manager needs information from actual spacing tests, such as those at Wind River, in reaching a decision.

The Experiment

In April 1925 the Pacific Northwest Forest and Range Experiment Station established a 14.5-acre plantation on a twice-burned Site IV (site index 110 feet) area at an elevation of 1,350 feet. The plantation was divided into six blocks to test spacing from 4 x 4 up to 12 x 12 feet. The 1-1 planting stock was grown in the Wind River Nursery from seed collected near Roy, Washington. During the first 3 years survival checks were made annually, and all dead seedlings were replaced. The plantations were remeasured at approximately 5-year intervals thereafter.

The fall 1951 measurements were taken on one 0.4-acre plot in the 12 x 12 foot spacing and on three 0.25-acre plots in each of the other spacings. Diameters of all trees over 1.5 inches were measured with a diameter tape. Heights of 40 trees in each plot were measured with Abney level and chain. A height-diameter curve was constructed for each spacing to use in estimat-

The author is Forester on the Gifford Pinchot National Forest. When he made this study, he was with the Pacific Northwest Forest and Range Experiment Station, Forest Service, U. S. Dept. Agric. He wishes to acknowledge the assistance of Leo A. Isaac, who was in charge of the experiment from its beginning.

ing volumes. On each plot the diameter of the tree with average basal area (dominant and codominant stand) was calculated. The height of this tree was read from the height-diameter curve for each spacing and used to estimate site index. The time since planting was used as the age.

Stand Development

The live stand. Several trends associated with spacing are evident in statistics for the 27-year-old plantation (Table 1). In trees 1.5 inches d.b.h. and larger, basal area and total-stem cubic volume decreased with wider spacing. On the other hand, in the stand 6.6 inches d.b.h. and larger, this trend was reversed in basal area and board-foot volume. Indeed, the 6,070 board feet produced by the 12 x 12 spacing is many times greater than the 268 board feet in the 4 x 4 spacing. Ingrowth soon will tend to level off this difference, but it is evident that the wide spacings have produced the most volume of large products (Fig. 1). The total-stem cubic volume in the close spacings is distributed on many small stems. Many of these will soon die. Statistics from a nearby natural stand are similar to the 8 x 8 spacing.

Growth and mortality. Periodic annual growth and mortality (Table 2) show how the plantation has changed during the most recent remeasurement period. The variation in total-stem cubic volume growth does not appear to be associated with spacing at this age. Judging by evidence on the ground, the variation is apparently associated with slight differences in site quality. The trend of board-foot volume growth is exaggerated by the heavier ingrowth in the wide spacings. Even so, the wide spacings are well ahead in board-foot production. Natural thinning is beginning in the 4 x 4-foot spacing, but the death of suppressed trees will probably do little toward releasing the crop trees.

Table 1. 1951 statistics of the live stand for each spacing, acre basis

Spacing (feet)	Stand 1.5 inches and over			Stand 6.6 inches and over			
	Number of trees	Basal area (sq. ft.)	Volume (cu.ft.)	Number of trees	Basal area (sq. ft.)	Volume (cu.ft.)	Volume[1] (bd. ft.)
4 x 4	1,830	132.0	2,320	8	2.4	61	268
5 x 5	1,480	112.8	1,890	6	1.5	34	137
6 x 6	1,030	103.8	1,870	30	8.6	191	753
8 x 8	580	78.6	1,470	67	19.8	425	1,690
10 x 10	405	91.2	1,950	166	57.7	1,282	5,500
12 x 12	287	80.5	1,740	176	65.4	1,460	6,070
Natural[2]	598	75.5	1,440	98	35.7	778	3,190

[1]International 1/8-inch rule.
[2]Data from a nearby natural stand of the same age.

Table 2. Periodic annual growth and mortality, 1945-1951, acre basis

Spacing (feet)	Annual growth			Annual mortality		
	Basal area (sq. ft.)	Volume[1] (cu. ft.)	(bd. ft.)	Number of trees	Basal area (sq. ft.)	Volume[1] (cu. ft.)
4 x 4	6.15	176.8	45	24.7	0.84	11.6
5 x 5	6.26	156.4	23	5.7	0.15	1.6
6 x 6	5.93	157.1	126	5.0	0.17	2.2
8 x 8	5.40	138.4	198	1.0	0.02	0.2
10 x 10	6.87	193.6	820	0.7	0.03	0.4
12 x 12	5.85	167.7	853	1.0	0.13	2.3

[1]Cubic volume for trees 1.5 inches and over; board-foot volume for trees 6.6 inches and over, by International 1/8-inch rule.

Fig. 1. Effect of spacing on tree size in a 27-year-old plantation of Douglas-fir. Trees are the same age and have grown under approximately the same conditions in both spacings. (Left) 4 x 4-foot spacing where trees average 3.6 inches in diameter and 33.7 feet in height. (Right) 12 x 12-foot spacing, trees average 7.2 inches in diameter and 46.2 feet in height.

Normality. The effect of spacing on tree height has affected site determination significantly. Therefore, in computing stand normality for the various spacings, a site index of 110 feet, from the nearby natural stand, was used. Normality for the different spacings computed for the conventional measures was as tabulated below.

Spacing	Number of trees *Percent*	Cubic volume *Percent*	Board-foot volume (*International 1/8-inch rule*) *Percent*
4 x 4	94	125	16
5 x 5	76	102	8
6 x 6	53	101	45
8 x 8	30	80	100
10 x 10	21	106	327
12 x 12	15	94	361

Even though the wide spacings were far below normal in number of stems at age 27 years, they were near normal in total-stem cubic volume and far above normal in board-foot volume.

The Average Tree

Height and diameter. The size of the average tree increased with wider spacing (Fig. 2). The average tree in the 12- x 12-foot spacing was twice the diameter of the average tree in the 4 x 4 spacing and was 12.5 feet taller. When the plantation was only 5 years old, the trees in the 4 x 4 and 5 x 5 spacings were taller than those in the wider spacings.[1] By the time the trees were 10 years old this trend was reversed and the difference in height has increased steadily ever since. Average diameter has followed a similar trend. During the most recent growth period, average diameter in the 4 x 4 spacing increased only 0.6 inch. During the same period, average diameter in the 12 x 12 spacing increased 1.9 inches.

[1]Isaac, Leo A. 1937. 10 years' growth of Douglas-fir spacing-test plantations. Pacif. Nthwest For. Range Exp. Sta. Res. Note No. 23.

Height of the average dominant and codominant. The spacing test provides evidence that density has a marked effect on the average height of dominant and codominant trees. After 27 years the trend was as follows:

Spacing (feet)	*Height of average dominant and codominant (feet)*
4 x 4	38.1
5 x 5	35.2
6 x 6	38.7
8 x 8	39.9
10 x 10	46.3
12 x 12	48.4

In general, wider spacing resulted in greater height growth. The average dominant and codominant in the 12- x 12-foot spacing was 10 feet taller than in the 4 x 4 spacing. If site is calculated in the accepted way for these two plantings, the difference in predicted yields in a 100-year rotation is about 19,000 board feet, Scribner volume.

This wide difference in indicated productivity does not seem reasonable for a planting area that is fairly uniform. The analysis casts doubt on the use of the height of the average dominant and codominant tree as a true index of site quality in young-growth stands. The codominants, at least, are strongly affected by spacing. There is an almost step-like break in the codominant crown level from the 4 x 4 spacing into the 10 x 10 spacing. This break is very apparent when looking from an elevated vantage point in the 4 x 4 plantation.

Would the heights of the tallest dominants alone be a better measure of site

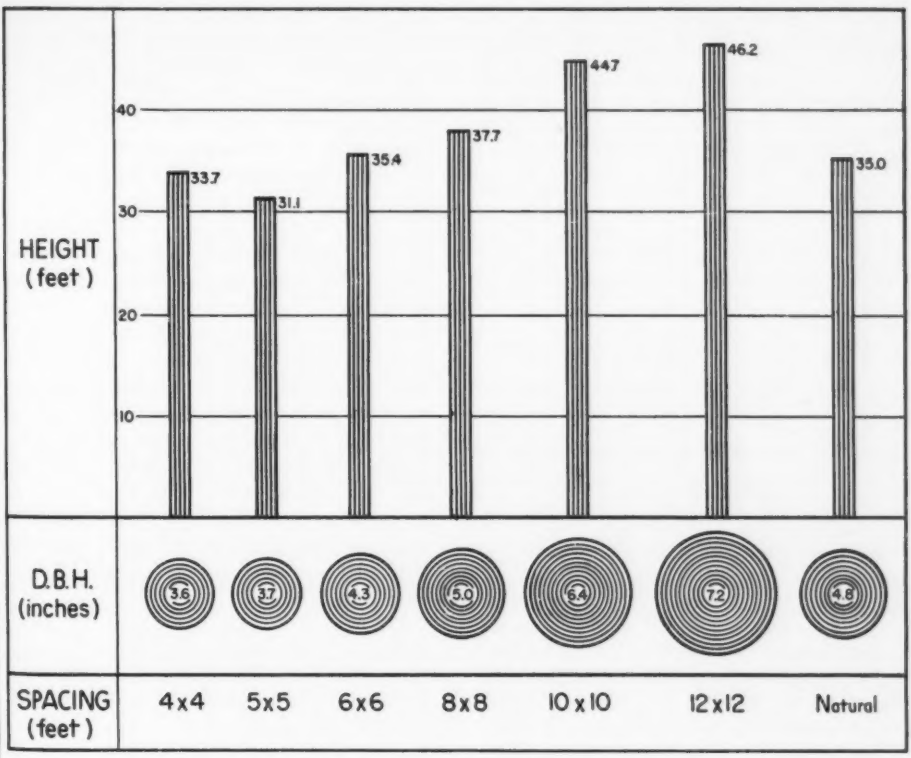

Fig. 2. Height and diameter of the average tree in each spacing at age 27 years.

quality? That they may be is indicated by calculating site index[2] from the average heights of the 6 tallest dominants on adjacent plots in the 4 x 4 spacing and the 10 x 10 spacing:

Spacing (feet)	*Site index using height of average dominant and codominant in 1951 (feet)*	*Site index using average height of 6 tallest dominants in 1953 (feet)*
4 x 4	100	125
10 x 10	120	137

Site index calculated from the average height of the 6 tallest dominants on a 0.25-acre plot is apparently less affected by spacing than site index measured in the usual way.

Limb size and height to live crown. The effect of spacing on limb size is often stressed.[3] In 1951 40 trees in each spacing were measured for limb size and height to live crown. Limb size was taken as the average of the 2 largest limbs in the whorl above and the whorl below d.b.h., measured 1 inch from the trunk. A tabulation of results follows:

Spacing (feet)	*Limb size (inch)*	*Height to live crown (feet)*
4 x 4	0.36	19.5
5 x 5	.43	13.7
6 x 6	.48	10.7
8 x 8	.54	8.9
10 x 10	.73	8.4
12 x 12	.73	6.7

An increase in limb size with wider spacing is apparent, but even the large limbs in the 12- x 12-foot spacing averaged less than three-fourths inch. These limbs are dead and will not make further growth. The limbs in the close spacings are small, but even in the 4 x 4 spacing little clear wood will be produced in a 100-year rotation without artificial pruning.[4]

Conclusions

Records from the 27-year-old spacing-test plantation of Douglas-fir indicate that:

1. Wide spacing in plantations has little effect on total-stem cubic volume in the first 27 years, but increases board-foot volume greatly.
2. Average diameter is greatly increased by wide spacing.
3. Wide spacing produces a taller dominant and codominant stand (and a higher site index when measured in the conventional way).
4. Average limb size is increased by wide spacing.

The findings should prove useful to the forest manager in deciding what spacing to use under a given set of conditions and objectives. His problem is to balance planting costs against estimated future returns. Planting costs per tree will be nearly the same regardless of spacing. Therefore, the wider the spacing (up to 12 x 12 feet on Site IV land), the lower the initial cost and the sooner material of sawlog size will be produced. Since, even in close spacings, pruning will be necessary to produce clear lumber in 80 - 100-year rotations, it may be best to keep planting costs low by spacing trees as far apart as 10 feet, with the expectation of pruning at an early age. If a 12-foot spacing is used, careful planting and early replacements may be necessary to avoid large openings. In contrast, where very early thinnings for small pole-size material are anticipated, closer spacing would be desirable.

[2]Staebler, George R. 1948. Use of dominant tree heights in determining site index for Douglas-fir. Pacif. Nthwest For. Range Exp. Sta. Res. Note No. 44.

[3]Munger, T. T. 1946. The spacing in plantations. Pacific Nthwest For. Range Exp. Sta. Res. Note No. 34.

[4]Kachin, Theodore. 1940. Natural pruning in second-growth Douglas-fir. Pacif. Nthwest For. Range Exp. Sta. Res. Note No. 31.

Genetic Control of Oleoresin Yield and Viscosity in Slash Pine

BY

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DURING 1941, a program aimed at the development of a superior strain of slash pine (*Pinus elliottii* Engelm.) for the production of naval stores was initiated at the Lake City Research Center.[1] Outstanding trees throughout the naval stores belt were selected for use in controlled pollination and vegetative propagation phases of the program. The first results of a progeny test for the inheritance of oleoresin yield are described in this report. The study consisted of three major phases:

1. Comparison of gum yield from the progenies of parents of known gum-yield capacities.
2. Measurement of physical factors which determine gum flow in the selected parents.
3. Study of inheritance of the physical factors which determine gum flow.

Literature Review

Improvement of plants through the selection of outstanding parents is a time-honored practice in agriculture. The rubber industry, an industry which also utilizes the products from living trees which exude as a result of wounding, has improved the yield of individual trees manyfold by budding scions from productive parents (Spring, 1926). As early as 1924, Heusser illustrated the benefits which can be derived in controlled crossing of high yielders, and also in collecting seed from open-pollinated flowers.

Slash pines which are morphologically alike show great variations in gum yield. Wyman (1932) found trees that were alike in all external characteristics but varied in their gum production by 100 percent, and in some cases even 300 percent.

The first recorded attempt to assess the genetic influence on gum yield of longleaf pine was initiated by Liefeld in 1935. He collected open-pollinated cones from two groups of trees of known gum-yielding capacities. One group had gum yields ranging from slightly above average to one and one-half times average, while in the second group the yields varied from slightly below average down to two-thirds of average. A test of gum yield of the 17-year-old progeny showed that gum yielding ability is

[1]At that time, a subdivision of the Southern Forest Experiment Station. The project was commenced under the direction of H. L. Mitchell. Selection, vegetative propagation, and control pollination were carried out by K. W. Dorman and C. S. Schopmeyer. A. G. Snow, Jr. assisted with the first control pollinations. Special acknowledgment is made to K. W. Dorman, who established the progeny testing plantation.

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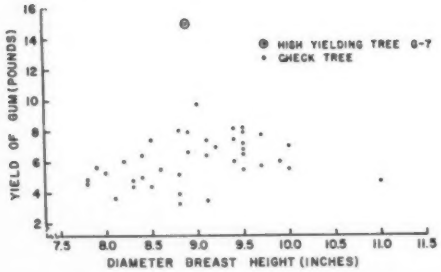

Fig. 1. Total yield for a 27-week check period in relation to diameter at breast height. High yielding tree fell outside the distribution pattern for that particular stand. The data for this graph were obtained from an office report on The Selection of Superior Slash and Longleaf Pine for Naval Stores Production, *prepared by K. W. Dorman in 1942.*

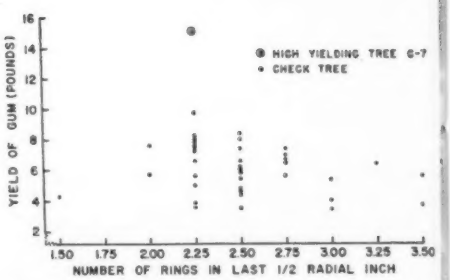

Fig. 2. Comparison of total yield of high-yielding tree with that of check trees in relation to number of rings in last ½ radial inch. The data for this graph were obtained from an office report on The Selection of Superior Slash and Longleaf Pine for Naval Stores Production, *prepared by K. W. Dorman in 1942.*

an inherited character in longleaf pine (Mergen, 1953). The possibilities of genetic improvement of the naval stores of the southeastern part of the United States were recognized during 1941 when a species improvement program was started at Lake City, Florida. The aims and progress of the program have been described in several publications.[2]

In Austria, Wettstein (1951) and Harm (1953) are making selections from *Pinus nigra* (var. *austriaca*) and the typical variety of *P. nigra* respectively for improved oleoresin yields. Machado (1953) has located outstanding individuals of *P. pinaster* for vegetative propagation and also for testing open-pollinated progeny in his program to obtain high-resin-producing trees for future stands in Portugal.

Dorman (1945) has discussed the possibilities of establishing turpentine orchards with high-yielding stock. These orchards would contain superior trees with twice the average yield capacities of normal stock. This procedure should bring about higher yields per acre and thereby increase the efficiency of turpentining.

[2]Mitchell, 1942; Mitchell *et al.*, 1942a and 1942b; Dorman, 1947; Downs, 1949; Mergen, 1953a.

Selecting slash pines for superior gum yields on the basis of morphological characteristics alone, without actually checking the yield, is unsatisfactory. Schopmeyer, *et al.* (1954) reviewed past work which tried to correlate characterisetics of pine trees with their yield capacity. The degree of correlation with any of these factors was not great. These workers demonstrated that the number and size of radial resin ducts exposed by chipping, and the reciprocal of the viscosity of the oleoresin, accounted for 83 percent of the variation in flow rate between trees. Attempts to measure exudation pressure accurately were not successful.

Materials and Methods

Selection of parent trees. During the initial stages of the program, the location of outstanding gum yielders was facilitated by the cooperation of naval stores operators and Naval Stores Conservation Program fieldmen. Promising trees were studied in detail by comparing their yield with that from 15 to 50 surrounding trees. The study trees were of the same age and in all cases within the group of check trees.

The turpentine faces were marked off and guide marks were painted on the tree to help the chipper keep the streaks uni-

form. The trees were chipped with a ½-inch wood hack at weekly intervals for 14 to 32 weeks, depending on the location of the study area. Yields were weighed in the field to the nearest gram on scales protected from wind currents.

All trees were rated on the basis of their diameter at breast height and their growth rate, because these two factors are associated with yield. Total yield data were plotted over d.b.h. and over number of rings per inch based on the last one-half inch of radial growth (Figs. 1 and 2). The yield of each superior tree was then compared with that of an average tree (obtained from the regression line) for the particular diameter or growth rate of the study tree. These averages served as a basis for selecting high- and average-yielding trees, which were designated by a "G" number for further identification. The relative yielding capacities of the selected trees are listed below.

Tree number	Yield rating (*multiple of average*)
G-1	2.11
G-2	2.00
G-3	2.17
G-4	2.00
G-7	2.46
G-9	1.75
G-10	1.71
G-11	2.12
G-28	1.87
G-6	.94
G-8	1.04
G-23	.98
G-25	1.00

Test of seedling progenies. The trees used in this progeny test resulted from controlled pollination studies during 1943 and 1944. The aims of the breeding work as set forth in office reports by Snow *et al.* in 1943, and by Dorman in 1946 were: (1) to produce high-yielding slash pines from crosses between high-gum-yielding trees, and (2) to compare the gum yields of the progeny from crosses between *high-yielders* with those of *High* × *Average*, and *Average* × *Average* crosses. In addition to the controlled crosses, open-pollinated seed was collected for testing.

The seed from the first breeding attempts was kept in storage until enough material for a suitable progeny testing plantation was on hand. During November 1945 the seed was sown in plant bands fitted into the propagation benches of a greenhouse. A single seed was sown per plant band. During the early part of June 1946, the seedlings were outplanted in a randomized block design on a better than average site. There were three replacement blocks in addition to the seven main blocks of the outplanting.

Spacing between the trees was 20 by 20 feet to allow each tree to develop freely with little interference from neighboring trees. At the time of the chipping experiment described in this report the average height for the plantation was 20.1 feet and the average d.b.h. was 4.7 inches. Prior to the actual experiment, in the fall of 1952, all trees in the plantation were pruned up to one-third of their height, to minimize and standardize the possible effects of knots and branches on gum yields. In Table 1 the crosses, yield classification, and the number of trees tested in each cross are given. Throughout this report the first tree in a cross denotes the female (♀) parent and the second the male (♂) parent.

Field and laboratory procedure. Three different techniques had to be used for the determination of gum yield, viscosity, and number and size of radial resin ducts.

The micro-chipping technique developed by Ostrom and True (1946) for naval stores research proved to be suitable for the determination of gum yield. By this technique, a square inch of bark and cambium was lifted out of every test tree with a metal punch, and the exposed wood was sprayed with 50-percent sulfuric acid to open the radial resin ducts. Two weeks later, a second wound was made directly above the first one, extending the total period of observation to 4 weeks. The resulting oleoresin flowed over a small metal

Table 1. Number of trees tested, by cross and by type of observation

Gum-yielding ability and cross	Gum yield	Viscosity	Resin ducts
High yielders × high yielders			
G1 × G2	28	5	----
G1 × G7	27	----	----
G3 × G2	26	----	----
G4 × G1	27	5	----
G10 × G7	28	----	----
G4 × G10	----	4	4
G4 × G9	----	8	8
G4 × G11	----	7	7
High yielders × wind			
G1 × W	38	9	----
G2 × W	37	----	----
G3 × W	37	10	10
G4 × W	18	11	11
High yielders × average yielders			
G3 × G6	----	7	7
Average yielders × high yielders			
G6 × G3	----	10	10
Average yielders × average yielders			
G6 × G8	27	10	10
Average yielders × wind			
G6 × W	36	11	11
G8 × W	17	10	10
G23 × W	33	----	----
G25 × W	39	----	----
Total	418	107	88

gutter into a glass vial clamped between the gutter and a nail in the tree (Fig. 3). Periodically the vials were changed and the gum measured to ±0.5 gram. Rather than let the streak width vary with three circumference, as is done in commercial operations, the experimenters made a standard-size wound, and for the analysis corrected the gum yields for the circumference.

All trees in the seven randomized blocks of the plantation were tested in this manner and the gum yields were measured during a 4-week flow period.

Sample trees for the determination of viscosity of oleoresin included 8 parent trees, 21 cuttings, and 107 trees from 6 selected progeny groups. The latter represented the combinations of *High* × *High*, *High* × *Average*, *Average* × *Average*, *High* × *Wind*, and *Average* × *Wind*. Viscosity samples of 2 grams were collected in small viscometer tubes from the first flow of gum produced by the wounded trees.

To overcome the difficulty of resin acids crystallizing out of solution, viscosity was determined in the laboratory within 24 hours after collecting the samples. The readings were taken by the bubble-rise method in which viscosity is expressed in stokes, or the time required for an air-bubble to rise over a certain distance through the liquid in a vertically mounted tube. The small tubes used in this test were calibrated against a standard Gardner viscometer tube. All samples were run in a water bath kept at 30° C. The viscosity of

each sample was calculated to the nearest stoke, based on two or more consecutive readings which did not vary more than 1 percent.

The number and size of radial resin ducts of the parent trees were measured on wood samples ½ inch by 1½ inches. The wood blocks were removed at breast height by means of the technique described by Echols and Mergen (1955). Tangential sections, 25 to 30 microns thick, were prepared with a sliding microtome at 5-ring intervals. They were stained with haematoxylin and safranin, and mounted for permanent reference.

Detailed measurements of radial resin ducts were made on 12 cuttings and on 88 progeny trees of crosses between known parents, and between known parents and wind. These wood samples were taken from the wound face with a ½-inch by 1-inch punch, which was driven into the trees with a mallet to a depth of ⅜ inch. The extracted samples were of sufficient thickness for clamping in a microtome. They were placed in individual, labelled vials and fixed for a minimum period of 24 hours in formalin-acetic acid-alcohol. No additional softening treatment was necessary before sectioning. From previous tests it was found that optimum thickness for counting and measuring radial resin ducts on tangential sections was about 30 microns. Sections of this thickness retained epithelial cell walls, sufficient ray parenchyma cells, and tracheids to differentiate sharply when stained. Two staining methods were used: (1) a safranin-fast green combination, which gave strongly contrasting red tracheids and light green parenchymatous tissue; and (2) safranin-haematoxylin, which outlined cell walls and emphasized the size and shape of the resin ducts. The stained sections were dehydrated and mounted on slides.

The total number of radial resin ducts per slide was determined under 100× magnification by means of parallel strips having the width of the field of vision. The average area for the sections measured was 3.24 cm².

Fig. 3. Micro-chipping method used to obtain oleoresin yields. Polyethylene bottle on right contained 50-percent sulfuric acid which was sprayed on the wood right after wounding. Gum collected in glass vials.

The average cross section of the radial resin ducts was determined by measuring their major and minor axes, including the thickness of the epithelial cells. For each tangential section a total of 10 resin ducts were measured with an eyepiece micrometer under a magnification of 440×.

Results

Difference in oleoresin yields between the four yield groups.—The total yield for each tree was corrected for the corresponding diameter at breast height to obtain a theoretical yield index for each tree. Under commercial naval stores practice the width of a face is equal to one-third the circum-

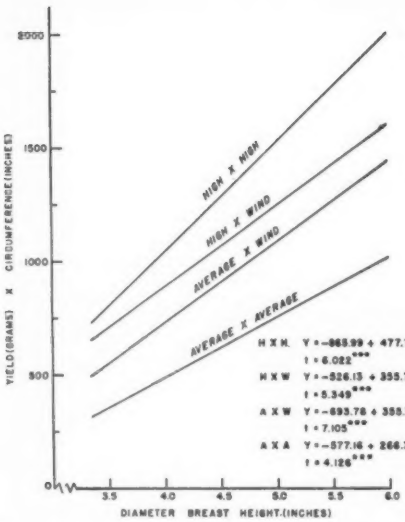
YIELD (GRAMS) X CIRCUMFERENCE (INCHES)
DIAMETER BREAST HEIGHT (INCHES)
HIGH X HIGH
HIGH X WIND
AVERAGE X WIND
AVERAGE X AVERAGE
H X H. Y = -868.99 + 477.71X
t = 6.022***
H X W Y = -326.13 + 355.75X
t = 5.349***
A X W Y = -893.78 + 355.75X
t = 7.105***
A X A Y = -577.16 + 266.35X
t = 4.126***

Fig. 4. Regression lines for yields of the four progeny groups: High × High, High × Wind, Average × Wind, and Average × Average. *The equation and statistical significance for each regression line is given.* (*** = *exceeds mean square error 0.1-percent level of significance*).

ference of the tree. In this study, the "yield index" of a tree was equal to the yield times circumference at breast height. Regression lines were fitted for the four yield groups using d.b.h. as the independent variable and yield index as the dependent variable (Fig. 4). The slope for each regression, *High* × *High, High* × *Wind, Average* × *Wind,* and *Average* × *Average* was highly significant, indicating a strong association between yield index and d.b.h. It should be recognized, however, that a high degree of association might be expected when both variables are functions of diameter. This regression is made up of two components of the yield index: (1) an increase in oleoresin yield per unit area of face width with an increase in size of tree, and (2) an increase in amount of face with an increase in d.b.h.

The difference in level between the four regression lines was highly significant when tested by analysis of variance. The difference between the level of the five *High* × *High* crosses and the level of the open-pollinated progeny from four *High* parents was highly significant. Yield index of the open-pollinated progeny from the *High* parents was highly significantly greater than that of open-pollinated progeny from four average trees. The trees in the *Average* × *Average* cross were lowest in gum yield. This particular regression consisted of only one cross (G-6 × G-8). Other tests with G-6 as female parent suggest that this particular tree actually is not an average producer but a low producer. The fact that the progeny from the *High* × *High* crosses outyielded all other crosses indicates that the genotype of some of the selected parents was better than average. How much better can not be determined at present.

It is reasonable to assume that pollination was of a completely random nature when the selected trees were open pollinated, and that pollen from both *high, average,* and *low* trees was available. This accounted for the smaller increase in yield as compared to controlled crossing with a high-yielding male parent. An "F" test of

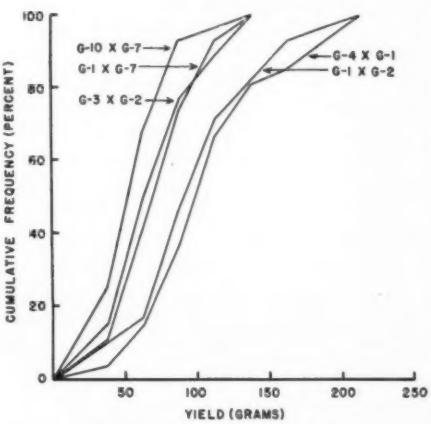

Fig. 5. Cumulative percentage frequency distribution of gum yields for the five crosses in the High × High *group. The rather prominent gap was significant at the 1-percent level.*

the variability between the open-pollinated progeny groups and that of the control-pollinated groups indicated a significantly greater variation within the open-pollinated progeny.

Difference within the yield groups. Within the *High* × *High* and *High* × *Wind* progenies there was a distinct division into two classes. This differentiation was more pronounced in the *High* × *High* progeny, where two crosses (G-4 × G-1, and G-1 × G-2) had outstandingly higher yields. An analysis of variance indicated a highly significant gap in the ordered series, separating G-4 × G-1 and G-1 × G-2 from the other three *High* × *High* crosses. The data on yield per unit of face for the *High* × *High* crosses were arranged in a frequency distribution, and, after these were plotted as a cumulative percentage frequency distribution, the spread between the groups became very apparent (Fig. 5).

The open-pollinated progeny of tree G-3

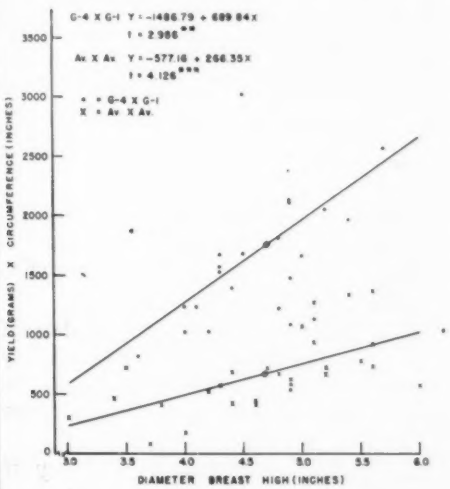
G-4 X G-1 Y = -1486.79 + 699.84X
t = 2.986**
Av. X Av. Y = -577.16 + 266.35X
t = 4.126***
• = G-4 X G-1
X = Av. X Av.
YIELD (GRAMS) X CIRCUMFERENCE (INCHES)
DIAMETER BREAST HIGH (INCHES)

Fig. 6. Comparison of highest yielding cross G-4 × G-1 with cross Average × Average. *Scatter of measurements is plotted to indicate extent of variation. Equations for the regression and their significance are also given.* (** = *exceeds mean square error 1-percent level of significance.* *** = *exceeds mean square error 0.1-percent level of significance.*)

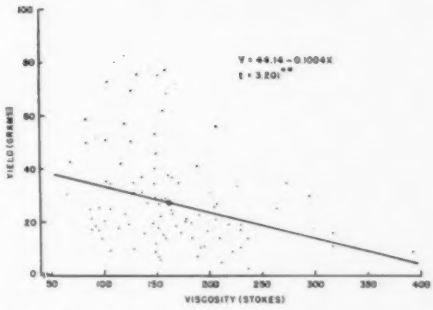

Fig. 7. Regression of yield on viscosity of oleoresin. Lower gum yields were associated with higher viscosity measurements.

gave lower yields than the open-pollinated progeny of trees G-1, G-2, and G-4, but the differences were not significant. It appears, however, that G-1, G-2, and G-4 are genetically superior gum yielders. It appears, further, that G-3, G-7, and G-10, although better than average, have genotypes that are not as superior as their original performance indicated. The yield from the progeny of G-7 × G-1 was much greater than that from the progeny of G-7 × G-10.

The outstanding cross of the study was G-4 × G-1. The yield index for its progeny in the 6-inch d.b.h. class was 1.8 times that of similar-sized progeny from *Average* × *Wind*, and 2.5 times that of trees from the *Average* × *Average* cross (Fig. 6).

Genetic control of viscosity. In a previous study (Schopmeyer *et al.*, 1954) it was established that viscosity of the oleoresin at the time of exudation from the tree significantly affected the flow rate during the inital 24-hour flow period. In this study, the viscosity was quite variable between trees and ranged from 49 stokes to 364 stokes. During the active growing season there is a pronounced change in viscosity, the highest value occurring at the beginning of the season and then decreasing rapidly. It appears to stabilize during the month of June. A high viscosity probably reflects a lower turpentine content of the oleoresin.

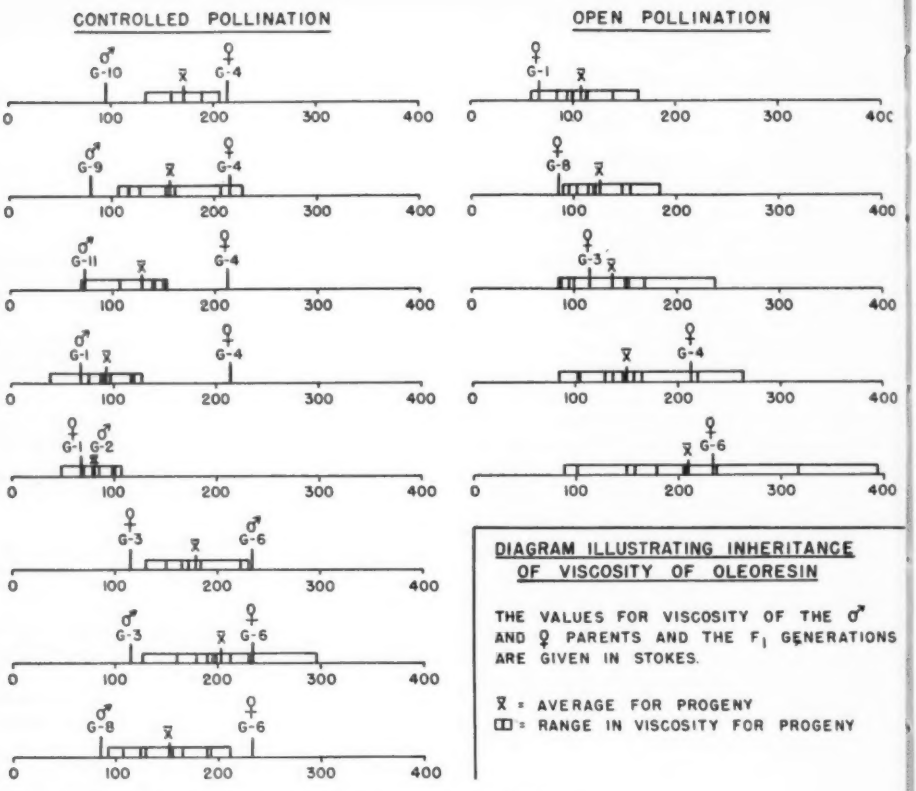

Fig. 8. Chart of inheritance pattern for viscosity of oleoresin.

Trees with thick oleoresin yielded significantly less gum than trees with thin oleoresin, according to the regression analysis of viscosity and gum yield of the progeny during the first 2-week period (Fig. 7).

To determine whether or not viscosity is a strongly hereditable character in slash pine, the viscosity of the rooted cuttings was compared with that of their parents. As can be seen from Table 2, there was a strong agreement between the viscosity of the cuttings and that of the trees (ortets) from which they were taken.

To portray the viscosity inheritance of controlled and open-pollinated crosses, the measurements of viscosities for the parents and the F_1 generations are diagramed in Figure 8. An analysis of these data shows several pertinent facts which can best be explained in terms of a multiple gene hypothesis. They are typical of findings in similar studies of quantitative characters.

1. The mean ($\bar{x}$) viscosity of oleoresin of the F_1 progeny is approximately intermediate between the parents. Average viscosity of the F_1 progeny

Table 2. Comparison of viscosity of cuttings with viscosity of ortets

Tree number	Ortets	Cuttings
	stokes	*stokes*
G-3	114	116
G-10	94	87
G-11	72	64
G-28	47	52

decreases with a decrease in one of the parents.

2. If a tree with a high viscosity is open pollinated, the average viscosity of the progeny is lower than that of the female parent, and a tree of low viscosity has open-pollinated progeny with an average viscosity higher than that of the female parent. Open pollination has an equalizing effect, bringing about progenies whose viscosity approaches that of the average tree in the population.

Both parents influenced the viscosity of the gum of their progeny. The viscosity of gum of five open-pollinated progeny groups showed a high degree of association with the viscosity of the female parents (Fig. 9). The regression was significant at the 0.1-percent level. In another test tree G-4 was fertilized with pollen from 4 different trees. Again the relationship between the viscosity of progeny and viscosity of parent was exhibited (Fig. 10). When tree G-4 was crossed with a male parent having low-viscosity oleoresin, the resulting progeny had a lower viscosity than when pollen from a tree with high viscosity was used.

Open-pollinated lots revealed a much greater variation than those from controlled pollinations. For convenience in presentation a smaller scale was used in Figure 9 than in Figure 10. This might obscure the difference in variation. However, an "F" test, using the residual sum of squares for each regression line, indicated a significantly lower variation in viscosity associated with the controlled crosses.

Variation in number and size of resin ducts. In the parent trees studied, the number and size of radial resin ducts was greatest in the area close to the pith and decreased toward the outer rings (Fig. 11). The number of resin ducts decreased very rapidly and between the 5th and 15th rings and levelled off after about the 20th ring. The average size of radial ducts decreased linearly as rings were added, no levelling off being apparent within the ages studied. No inheritance pattern was discovered for either number or size of resin ducts, from the measurements taken on the progeny. A regression, however, of *number* × *size* for each parent and progeny was significant at the 5-percent level. Whether or not these individual characteristics are under strong genetic control can not be determined at this stage of the study. One possible reason for the lack of high correlation was the young age of the progeny. Sampling was carried out during a period when a small

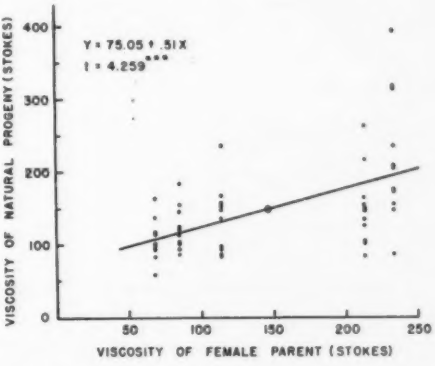

Fig. 9. Influence of female parent on viscosity of natural progeny.

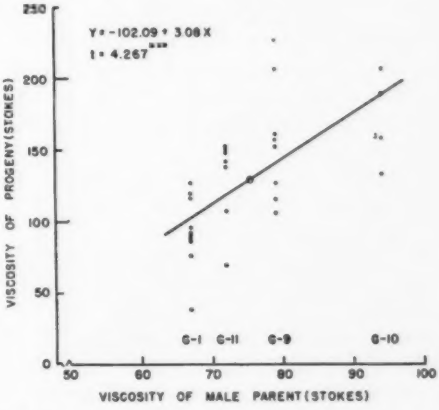

Fig. 10. Effect of male parent on the viscosity of the progeny of the seed parent G-4.

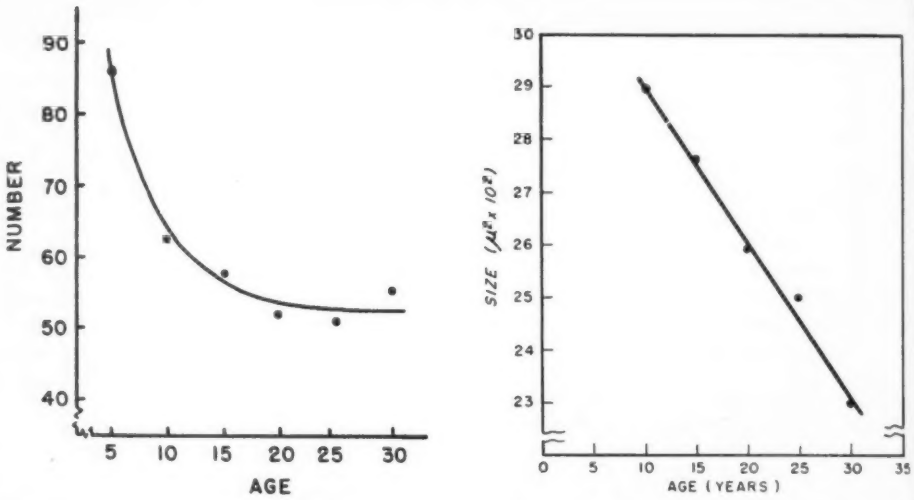

Fig. 11. Effect of age on number (left) and size (right) of radial resin ducts in parent trees.

change in the age results in a large fluctuation of both number and size of resin ducts. A resampling would be desirable some 15 to 20 years hence when the rapid change in the number of ducts has levelled off.

A regression analysis of size on the number of resin ducts showed a significant association between these two characters in the trees of the F_1 generation. Trees with more ducts have smaller ducts, and vice versa. This indicates a possible linkage between these two characters.

Evaluation of parents by physical characteristics. The number and size of radial resin ducts and the viscosity of the oleoresin were measured on the original selected trees in an effort to determine the factors which made these trees outstanding in their yield performance. For the group of parent trees tested, the function *number* $\times$ *size/viscosity* was not significantly related to gum yield of the progeny. Tree G-6 whose progeny gave the lowest yield of all the groups had the lowest value for this function, but the superior genotype G-4, whose progeny rated highest in the gum-yield test, also had a low value. This brings out one important shortcoming in this type of evaluation, namely, that not all of the physical factors can be measured with our present techniques. The exudation pressure, for example, may be of great significance, but so far all methods to obtain a reliable estimate for this value have failed in slash pine. Other factors which remain to be measured are: rate of oleoresin synthesis, surface tension of oleoresin, rate of crystallization, storage capacity (vertical resin ducts) within the effective area, and probably many more.

Discussion of Results

By carefully screening many thousand slash pines, it has been possible to select parent trees whose progenies have higher than average oleoresin yields. The parent trees were selected because of a superiority of approximately 100 percent over that of the average for the stand. The yield of progeny resulting from crosses of selected trees was less than the yield of the parent trees. Retrogression is common where traits are neither dominant nor recessive. The undesirable genes segregate out in consecutive generations and the value for the progeny regresses toward the average of the original population.

There was no control over the pollen

source of the trees producing open-pollinated progeny. Because most of the pollen came from average trees, the retrogression toward the mean of the population was pronounced. Therefore, the benefits obtained by collecting open-pollinated cones from carefully selected high-yielders will bring about only a mild improvement over randomly collected cones.

The viscosity of the oleoresin followed a well-defined pattern and the variations appear to be rigidly controlled by the genotype. Viscosity and color of the oleoresin in rooted cuttings was very similar to that of the ortets, indicating that these characters are strongly heritable under varied environmental conditions. The inheritance of viscosity was apparently neither dominant nor recessive, but probably was determined by a number of genes. By following through with the F_2 and F_3 generations a clearer understanding will be gained.

From the study of the inheritance of viscosity it appears that selection for high gum yield in slash pine should be effective because at least this determining factor is hereditary.

Practical Aspects

Some of the selected superior trees transmit their superior traits, whereas others do not. Sorting the former from the latter will be a continuing process. Steps have been taken to mass produce seed from the best parents. Grafts have been established for two types of seed orchards: (1) in an area isolated from stray slash pine pollen for the purpose of random pollination between the clones and (2) in a graft orchard where control pollinations will be carried out (Fig. 12). When further results from progeny tests are available, inferior clones will be removed from these seed orchards and replaced with proven superior genotypes.

Conclusion

A study of the oleoresin yield and viscosity of slash pine resulted in these findings:

1. Gum yield is an inherited characteristic. The progeny from outstanding phenotypes produced larger quantities of gum than average trees. Not all of the selected trees, however, proved to be superior genotypes.

2. Viscosity of oleoresin is under rigid genetic control.

3. In the age class sampled, the number and size of radial resin ducts changed rapidly with an increase in age. This factor probably accounts for the lack of correlation between parents and progeny in respect to these characteristics.

4. The progeny lots from open-pollinated sources showed a much greater variation than those from controlled crosses.

5. Establishment of seed orchards to

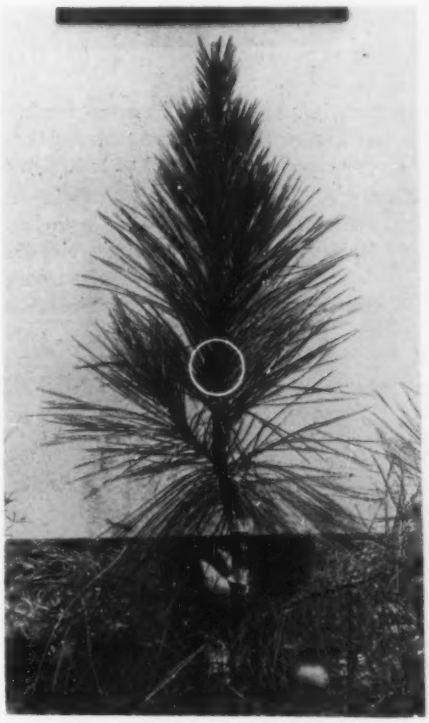

Fig. 12. Grafted slash pine from selected high yielders in seed orchards. The two conelets (circle) are in their first year of development.

mass produce seed of superior trees is a practical step toward improving the oleoresin yield of slash pine.

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Why Joint Saws?

BY

L. H. REINEKE

SAW FILERS are generally advised to joint saws before filing, or to use an automatic grinder, to make all teeth the same height. The theory is that each tooth then carries an equal load.

The advice is sound, but the theory that tooth loads are equalized by making the teeth uniform in height has been exploded. The ammunition for this explosion came from a long series of energy tests of saw teeth at the U. S. Forest Products Laboratory.

Test Method and Equipment

These energy tests were made on a pendulum dynamometer, a device designed by the author to measure the energy consumed in making a cut in wood with any type of cutting tool. As shown in Figure 1, two pendulums are swung from an arched framework, the near one carrying a holder for a cutting tool, the far one carrying a test sample holder.

The principle of operation is simple. If the tool pendulum is allowed to swing freely from a given height on the left, it will rise to a certain height on the right of the center. If, next, a sample of wood is attached to the test sample pendulum and positioned so that the tool will cut into it as it swings by, then the height of swing to the right will be less than the free swing, assuming identical starting heights. The difference between the two final heights is due to absorption of energy in making the cut. This absorbed energy is computed readily from the heights involved. The test sample pendulum, hanging free, is moved by the energy transferred to the wood in making the cut, but this movement is relatively slight, since most of the cutting energy is dissipated in the chip. The precision and high sensitivity of the dynamometer provide data not generally obtainable otherwise.

Distribution of Energy Expended in Sawing

The distribution of the energy used in making a cut with a chisel-type saw tooth is of interest. A portion of this energy goes into the severing of the fibers along the path of the cutting edge. This is constant, for a given tooth sharpness, regardless of the thickness of chip (the feed per tooth), because the same number of fibers must be severed whether the chip is thin or thick.

A second portion of the energy goes into detaching the sides of the chip from the kerf walls by shearing, and the energy required for this increases with chip thickness, since the shearing area on each side of the chip is the product of thickness and length.

As the chip is cut and sheared free, it must bend over the face of the tooth. A third portion of the energy goes into this

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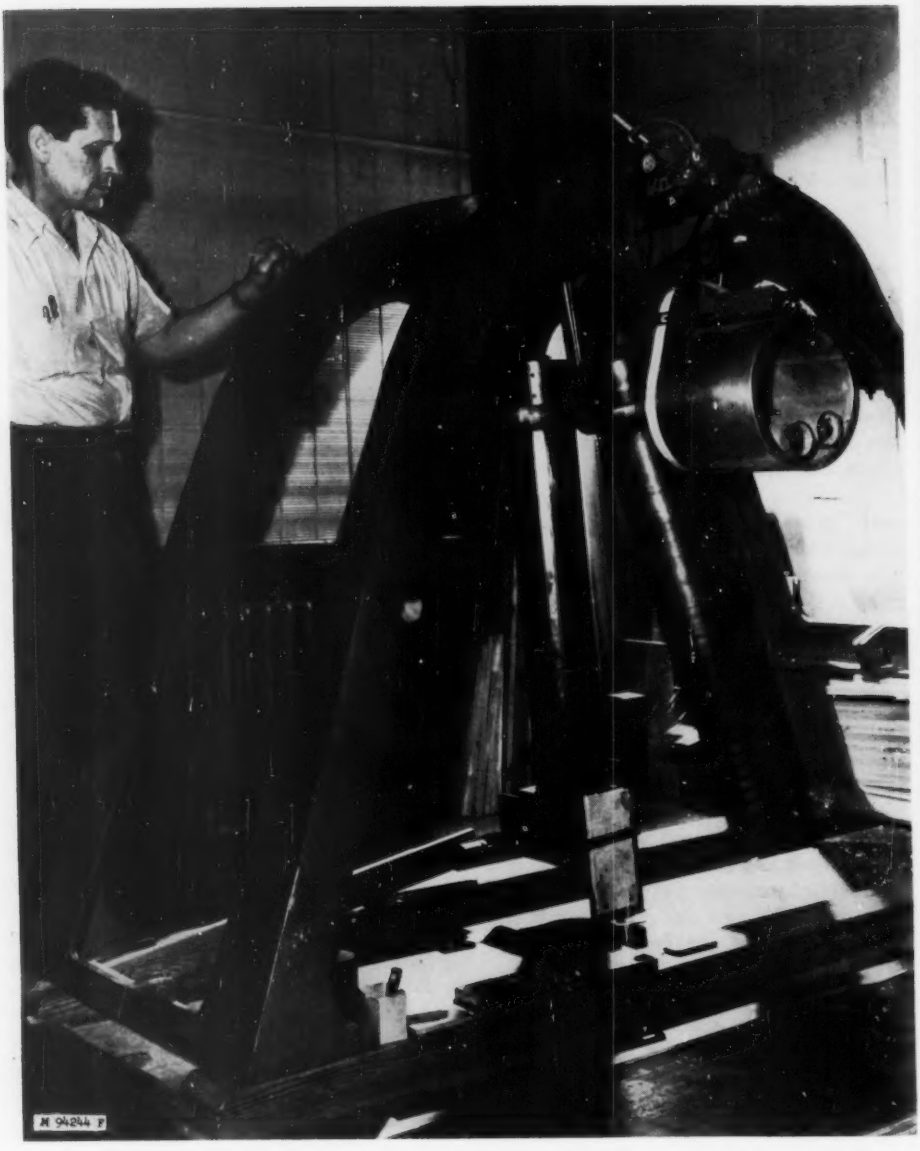

Fig. 1. Making a test cut on a pendulum dynamometer. (*Photo courtesy the Milwaukee Journal.*)

bending, but, since wood is relatively stiff and the angle it is bent through is rather large, the bending results in numerous fractures across the chip (except for extremely thin chips and small sharpness angles). This crosswise breakage results in a granulated chip (sawdust), and the energy absorbed increases with chip thickness, since the area of each cross break varies directly as the thickness of the chip.

The removal of the broken chip or sawdust from the kerf is a fourth factor in the absorption of energy. The chip width equals the kerf width, and the shearing at the chip edges leaves both chip and kerf surfaces rough, setting up a frictional drag on the chip particles during their removal. This is further increased by wedging action as the particles get tipped in the gullet. The energy required for chip removal is proportional to the frictional area of the sawdust, which, of course, depends on chip thickness.

These four subdivisions of energy[1] bear straight-line relationships to chip thickness, and it might be expected that the total energy absorbed could be rather closely determined for a given chip thickness and material. As a matter of fact, it can be—on the *average*. An unusual situation exists, however, in ripsawing. The material may be absolutely uniform in all its physical characteristics, but the sawing act itself may modify the material yet to be cut. To understand this fully, a knowledge of the details of cutting by a single ripsawing tooth is necessary.

Figure 2 shows the cutting edge of a chisel or swaged ripsaw tooth in the process of ripping at an attack angle[2] of nearly 90°, as occurs in bandsaw ripping, or near the bottom edge of logs on a circular headsaw

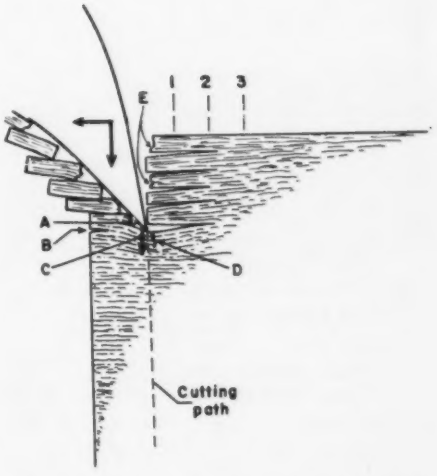

Fig. 2. Action of swaged ripsaw tooth in process of ripping.

carriage. The arrows on the tooth indicate the direction of the forces the tooth applies to the wood. The horizontal component exerts a wedging force that shears the sides of the chip free from the kerf walls, and, in tending to bend the chip up the tooth face, causes it to break crosswise by shear or bending failure along the grain.

The downward force component is applied by a variable area of the tooth face. At the instant the cutting edge touches the wood, the contact zone is merely a line, and all the downward force is applied to severing the fibers along the cutting edge. As the tooth moves down, more and more of the tooth face comes into contact with the wood, causing some compression of the wood at *A*. The maximum contact area is reached when the forces on the wood reach the point at which wood failure occurs and a portion of the chip breaks off. The plane of failure, *B*, crosswise of the chip, is near the cutting edge, and at the instant of failure the contact area immediately decreases to a line or very narrow zone at the cutting edge and again begins to increase as the tooth advances. This cycle is repeated each time the chip breaks across. The breaks are

[1]Additional energy is required to accelerate the chip from a stationary condition to the velocity of the saw teeth; it is related to chip weight and saw tooth velocity, but this is relatively minor unless saw tooth velocity is excessive.

[2]Angle between direction of fibers and path of cutting edge.

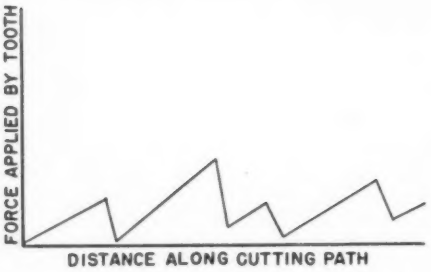

Fig. 3. Graph of force over distance in ripping with a swaged ripsaw.

not regular, however, and a graph of force over distance may appear as a series of gradual rises at a fairly constant slope, but of different durations, followed by sharp drops which may or may not reach a zero value, as indicated in Figure 3.

Whether the rising and falling portions of the graph are straight-line or otherwise is immaterial. As the contact area increases, the vertical component of the force presses downward on the chip. This pressure is resisted by the compression of the chip and the material to the left of the cutting path and below the edge. These forces induce tension perpendicular to the grain beyond the cutting path in the vicinity of the cutting edge, as at C. Figure 2, and, since wood is weakest in this direction, failure may occur in the form of advance cleavages or splits extending to the right, ahead of the cutting path, as shown. Fracture also may occur beyond the cutting path, as at D, resulting in breakouts such as E, earlier in the cut.

Every fracture, every split, every deformation of the wood demands its own quota of energy from the saw tooth. Conversely, every fracture or split already existing in the chip being cut reduces the energy demanded of the tooth, or the resisting force of the wood, during that cut. The resisting force of the wood is, of course, opposite and equal to the force on the tooth, and uniformity of tooth forces, under fixed feed and speed conditions, is contingent on uniform solidity in the wood.

Modification of Wood in Path of Saw

Solidity of material in the cutting path, however, may be impossible to maintain. With a very sharp tooth, a large hook angle, and a very thin chip, the tooth face pressure may be low enough not to produce splits in the fibers ahead of the cutting path. With a dull cutting edge, small hook, and fast feed, the tooth face pressure against the thick chip is almost certain to result in some splitting ahead of the cut. This modification of the material by the cutting act itself may have either a variable or a constant effect on the tooth forces.

The effect of this modification of material is rather unpredictable as to degree, since local variations in grain or in tensile strength across the grain may have a marked effect on the length of splits or occurrence of fractures. In any event, the advance splitting produced by one cut requires its own additional quota of energy, while the energy for the succeeding cut is correspondingly lessened by the pre-existent splits.

The shift in energy requirements between successive cuts can be rather large, depending on the frequency of advanced splitting and the relation between length of split and chip thickness. From Figure 2 it is evident that a cut made along line 1 will produce a chip in which the advance splits extend entirely through the chip, requiring a minimum of energy from the tooth. Little extension of the existing splits would be expected. Along line 2, at the ends of the advanced splits, below average energy will be needed if the splits are not extended, as might be the case if the cutting edge is sharp and hook angle large. A cut along line 3, however, would be entirely in solid wood, where resistance is high and the tooth-face pressure would induce advance splitting, resulting in high energy requirements and tooth forces.

Results of Dynamometer Measurements

The variation in forces involved in suc-

cessive cuts, and the unpredictability of them, is well substantiated by the dynamometer measurements previously mentioned. In making these measurements, a single saw tooth was used at a constant speed and the test wood sample was fed toward the tooth in uniform steps by a micrometer screw. Energy readings were made for each cut and recorded in sequence. Examples of these measurements are graphed in the sequence of cutting in Figure 4, A to E.

Section A of this figure illustrates an instance in which the force on the tooth, or energy consumption, alternated with great regularity between two values. This might result when one cut is in solid wood and the following is at the bottoms of the advance splits, leaving solid wood for a repetion of this cycle.

In section B, however, the spacing of cuts is not related exactly to the length of splits. Thus, for a chip thickness or feed of 12.5 mils[3] the series of measurements form a graph approximating a sine curve of very small amplitude. As the feed is increased to 50 mils, a fairly steady alternation between high and low tooth forces results. When the feed is further increased, to 100 mils, the alternation of high and low energies or forces persists, but stabilized at a range smaller than the 50-mil range after the first few cuts complete the transition to the new conditions.

A stabilized alternation of forces does not necessarily develop. This situation is illustrated by section C. The sine wave for the 12.5-mil feed has slightly smaller amplitude than in B, but when the feed was increased to 75 mils, the pattern became a modulated wave form due to "hunting" as the forces sought to stabilize but failed because the advance splitting and feed rate were not in proper relation to each other.

The proper relationship between advance splitting and feed seems to have occurred with both the 12.5-mil and the 75-mil feeds illustrated in D. The 12.5-mil cuts in this sample showed no cyclic trend,

[3]1 mil = 0.001 inch.

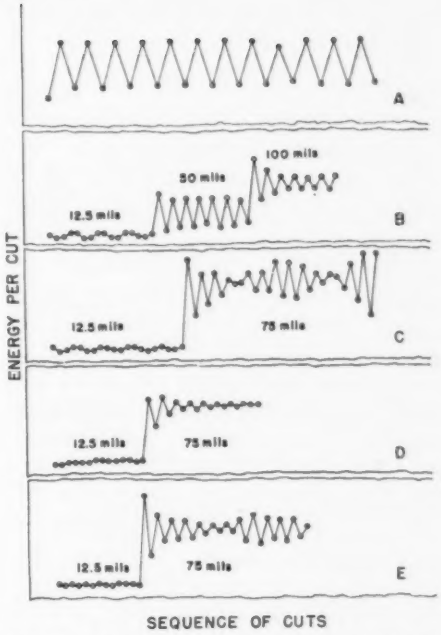

Fig. 4. Fluctuations in energy from tooth to tooth may be uniform (curve A) or may follow various cyclic patterns (curves B to E), depending on cutting conditions.

as in B and C, and on changing to the 75-mil feed the effect of the transition was quickly damped out and a steady-state condition was reached.

Achievement of a steady-state condition at one feed rate is, however, no assurance of a steady-state condition at another feed rate, as E well illustrates. In contrast with the sine curve in C for 12.5 mils, the graph in E at this feed shows what is practically a steady-state condition that is not matched when the feed is increased to 75 mils.

Unequal Forces on Saw Teeth

The few examples given here, typical of all the many measurements made with various species, tooth angles, degrees of sharpness, and the like, show that the forces on saw teeth may fluctuate widely between successive cuts (a 2:1 ratio is not uncom-

mon) even though chip thickness, tooth velocity, and material are highly uniform.

With this evidence of oscillatory or rhythmical variation in loads on uniform saw teeth, which could well be the source of some saw blade vibration, it is obviously futile to hope that tooth forces will be equalized by jointing.

Why Jointing Is Worthwhile

Although forces on saw teeth cannot be equalized by jointing alone, it is worthwhile for other reasons. With the uniform tooth height produced by jointing, a uniform tooth shape can be maintained more readily. Tooth marks, if of importance—and they may be in sawed glue joints—will be regularly spaced. Teeth of excessive height will dull more rapidly than the normal teeth, and dull teeth are enemies of good sawed glue joints. The additional height of the high teeth in an unjointed saw does impose an added stress (perhaps augmenting, perhaps counterbalancing the variable forces discussed above), and this may trigger a period of saw vibration. In deep cuts, high teeth definitely are undesirable because they take a bigger bite, and the resulting extra sawdust may overload the gullet and cause snaking, heating, or vibration.

Research has uncovered the previously unrecognized fact that the material cut and the cutting act itself may introduce variations causing saw misbehavior. In a properly jointed saw, any misbehavior that is due to the variations in force from tooth to tooth may be corrected merely by a change in feed rate.

Obchshee Lesovodstvo. (General silviculture).

By M. E. Tkachenko.

Second Edition. 1952. Goslesbumizdat, Moscow and Leningrad. (Russ.) R. 22.10 ($3.00). 599 pp.

REVIEW by E. V. Bakuzis
University of Minnesota

E. M. TKACHENKO (1878-1950) was a celebrated teacher at Leningrad's Forest Institute and an authority on the northern forests of Russia. The second edition of his general silviculture text, published posthumously, emphasizes Russian authors, Michurin-Lysenko biology, and Soviet philosophy. American readers may trace back the *Origin and propagation of forestry ideas* as presented by Tkachenko in the *Journal of Forestry* (28: 595-617) in 1930. Relicts are still present in the book published in 1952.

The book is divided into two parts: silvics, and silvicultural systems. Six of the chapters on practical silviculture are written by Asoskov while Melekhov wrote the chapter on the history of forestry in Russia. Soviet writings tend to be four-dimensional; and it is sometimes difficult to recognize the political dimension and evaluate its effect on the technical facets of Russian silviculture.

Photoperiodic changes and vernalization play an important part in Soviet thinking, particularly with reference to acclimatization. Many examples are cited. Michurin emphasized light as an important factor in acclimatization. Bogdanov (1928) and Moshkov (1929) used photoperiodic changes in the acclimatization of *Robinia*. Nursery plants supplied with artificial light have been found to grow much faster, even after being transplanted in the field. *Pinus radiata* develops flowers in the first year when given additional light. Ultraviolet

light can be used to hasten the extraction of seeds without detrimental effect on seed viability. Nikitin and Malcheskov, however, tried to speed up flowering and seed production of several woody plants working along the lines of Lysenko's theory of phasic development, but without success.

According to Tkachenko, Soviet silviculture is based upon the following theses by Lysenko: (1) Organisms and environment form a functional unit. (2) Vegetation develops in phases, and each phase has specific requirements of environment. Only two phases are known at present: jarovization or temperature phase, and the light phase connected with photoperiodism. (3) Heredity may be changed by environment; and (4) There is no competition between the individuals of the same species.

The study of forest types is another phase of silvics of major interest in Russia. In the present edition, the forest-type concept is credited to early foresters mapping for management purposes. Although Tkachenko and many other Russian authors in their earlier works recognize the independent development of *Finnish forest types*, Melekhov in his chapter claims that Cajander borrowed the idea from the Russians and that *the world sooner or later will learn this fact*. Morosov, the Russian authority on forest types, arrived at the following factors as being important in forest classification: (1) inner ecological properties of species, (2) geographical environment, (3) bio-sociological relationships between plants and plants and between plants and fauna, (4) land-use and geologic history, and (5) action by man. Sukachev, currently the best-known Russian forester abroad, has numerous publications on forest types, some written in German and English.

It is of interest to read that larch covers 250 million hectares in the U.S.S.R. and is the most widely distributed conifer genus. *Larix sibirica* grows from the frozen tundra to semi-arid zones. Due to its tolerance to gypsum soils, it forms extensive forests near Archangelsk which are not invaded by shade-tolerant species.

Coming to practical silviculture, the forests of the U.S.S.R. are now divided into three groups: (1) protection forests, (2) conservation forests, and (3) exploitation forests. The second class are largely restricted to the center of the Russian federative republic where deforestation has been extensive. Here the cut is limited to increment. Elsewhere, the cut is determined according to the growing needs of Soviet industries.

The selection system is impractical in the exploitation forests at present. In any event, Alexejev and Molchanov have concluded that production in clearcut even-aged forests is greater than that in selection-cut even-aged forests. Even in uneven-aged forests, clearcutting does not result in lower increment.

Turning to thinning, a good rule-of-thumb is to cut the stand so as to expose from one-fifth to one-third of the ground to sunlight. Tkachenko admits that *reactionaries* were right in their conclusions that thinning can not significantly change the total volume production, and that *progressivists* have wasted much time in stubbornly hanging on to this problem. All *stakhanovites* are invited to work on the mechanization of thinning.

Finally, the history of forestry in Russia is relatively long. The first book in Russian was written by the German forester Fokel in 1766, *but his forestry knowledge is a reflection of the ideas of Lomonosov and the Russian environment*. The first school of forestry on a university level was established near Petersburg (Leningrad) in 1803. *Lesnoi Zhurnal* (now *Lesnoi Khoziaistvo*), the journal of forestry, first appeared in 1832. An enormous reforestation project in the steppes was started in 1948. Up to 1950, 2.6 million hectares had been planted, with the goal being an additional 5 million by 1955.

All in all, one emerges with the feeling that Russian silviculture is competent but not outstanding to the extent that it can be judged in a book that presents scientific and technical data mixed with a dose of politics.

Evidence of Races of Cronartium ribicola on Ribes

BY

RALPH L. ANDERSON
DAVID W. FRENCH

EVIDENCE of races of white pine blister rust, *Cronartium ribicola* A. Fisch., has been obtained in a recent study. The leaves of *Ribes nigrum* L. plants were inoculated with aeciospores collected from various species of five-needle pines in different parts of the country (Table 1). Uredospores produced on these plants by the various collections of rust were used to inoculate a clonal line of *R. hirtellum* Michx. propagated by rooting cuttings. The *R. hirtellum* plants were kept under the same conditions in a greenhouse and from 2 to 4 rust collections, each on a separate plant, were compared in a given test.

The clone of *R. hirtellum* was initially tested as a differential in 1953. Large necrotic areas surrounded by a chlorotic zone were produced by spores of a collection from *Pinus lambertiana* Dougl. Large chlorotic spots with no necrosis were produced by spores of a collection from *P. strobus* L. In 1954 further tests were made using new aeciospore collections. Four collections from *P. lambertiana* produced the necrotic reaction. Five collections from *P. strobus* and one from *P. monticola* Dougl. produced the chlorotic reaction (Table 1). Each test included both eastern and western collections of aeciospores. The above described reactions were observed about 20 days after inoculation. Typical examples are shown in Figure 1.

Additional work will obviously be re-

Table 1. Hosts, geographic sources, and infection type of aeciospore collections

Host	Location	Number of collections	Infection type
Pinus strobus	West Virginia	1	Chlorosis
P. strobus	Vermont	1	Chlorosis
P. strobus	New York	2	Chlorosis
P. strobus	Minnesota	1	Chlorosis
P. lambertiana	California	4	Necrosis
P. lambertiana	Oregon	1	Necrosis
P. monticola	Oregon	1	Chlorosis

Anderson is pathologist, Lake States Forest Experiment Station, Forest Service, U. S. Dept. of Agriculture. French is Assistant Professor of Plant Pathology, Agricultural Experiment Station, University of Minnesota. The authors wish to thank Dr. E. C. Stakman for his advice on methods of conducting the study and evaluating the results.

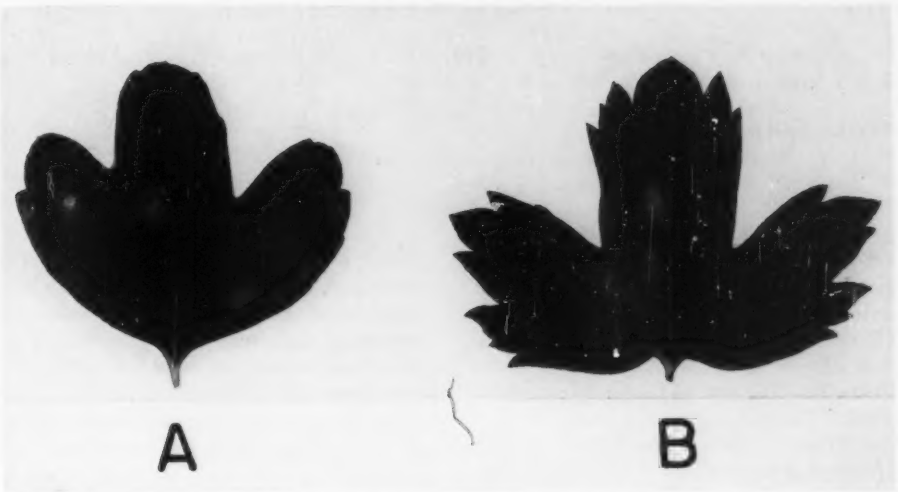

Fig. 1. Twenty-day-old uredial pustules of Cronartium ribicola *on a clone of* Ribes hirtellum. A, *Inoculum from* Pinus strobus *from Vermont has produced chlorosis only.* B, *Inoculum from* Pinus lambertiana *from Oregon has produced necrosis plus chlorosis. Leaf A is younger than B and also has dust on its surface. The reaction to inoculum from a given source was constant despite such variations in the leaves.*

quired to determine whether *C. ribicola* contains few or many races. Nevertheless, the results here reported indicate that such races apparently do exist. Whether the reactions obtained on Ribes indicate that there are physiological races of the rust that vary in pathogenicity on the pines can be determined only by inoculation of the respective five-needle pine hosts. This would apply to the further testing of pines already selected for resistance to the rust. It would also apply to testing the rust resistance of new strains, varieties, and hybrids of white pines that may be selected or produced in the future.

Many tests have been made on other Ribes hosts during the past 4 years. The following species have been used: *R. nigrum*, *R. petiolare* Dougl. *R. cynosbati* L., *R. hirtellum*, *R. lacustre* (Pers.) Poir., *R. cereum* Dougl., *R. americanum* Mill., *R. punctatum* Ruiz et Pavon, *R. meyeri* var. *turkestanicum* Jancz., *R. viburnifolium* A. Gray, and the horticultural variety Viking (*R. petraeum* Wulf. × *R. rubrum* L.).

In general, these species did not show the differences in infection type as reported for the clonal line of *R. hirtellum*. In a few tests, though, lesser differences in reaction have been noted on *R. meyeri* var. *turkestanicum*, *R. cynosbati* and *R. lacustre*. Further testing must be done, however, to establish whether these differences are due to genetic factors. The horticultural variety Viking and *R. viburnifolium* have been included in some tests but have not become infected by any of the spore collections used.

Manual of Malayan Timbers. By H. E. Desch.

Vol. I, Caxton Press Ltd., Kuala Lumpur. 1941. $40. (Straits dollars). Vol. II. Malayan Publishing House Ltd., Singapore. 1954. $15 (Straits dollars). 762 pp.

REVIEW by Harold A. Core

College of Forestry, State University of New York.

Ordinarily, it might be expected that the various volumes under a single title would be published simultaneously or follow in order within a reasonable length of time. However, due to wartime circumstances, Vol. II. of the above manual, (Malayan Forest Records No. 15), was delayed until 1954. The author was a prisoner of war, during which time a considerable amount of material and valuable information were either lost or misplaced. Mr. Desch deserves considerable credit for his perseverance in completing this excellent work.

Even though the publication dates of the two volumes are widely separated, it seems logical to review them together. Pagination is continuous and an alphabetical sequence of families is followed. Vol. I. includes 45 families of Angiosperms from the Aceraceae through the Malvaceae; and Vol. II. includes 34 families from the Melastomaceae through the Winteraceae. The few conifers are included under Coniferales in Vol. II.

The author follows Hutchinson's *Families of Flowering Plants* in his descriptions with few exceptions. Most readers will have little difficulty in using the book since he has been quite precise in describing the families. Where there is disagreement in classification of families, genera, or species, the author has gone into considerable detail in summarizing the arguments.

Without materially increasing the size of the manual, it is difficult to visualize how more information could be condensed in the two volumes. A type description has been given for each family which includes size, occurrence, economic importance, summarization of anatomical structure, and representation in the Malay Peninsula.

The individual timbers are covered in detail: general properties, features useful in identification with naked eye or with a lens, mechanical properties, working qualities, seasoning, and, where available, impregnation tests, usually are included. There are excellent 5× photomicrographs of the cross-sections of many of the important timbers. Macroscopic and microscopic features of certain species are summarized in chart form.

Regrettably, at least to this reviewer, some of the appendices originally planned to be included have been omitted. Uses of Malayan timbers, card-key to lens characters, and glossary of Malay words were not included. The first two seem rather important, and it is hoped that they will be published eventually. Appendices remaining are (1) figures on mechanical properties collected from pilot tests, (2) list of plates, (3) bibliography, (4) citation of material, (5) index to scientific names, and, (6) index to vernacular and timber names.

A mild criticism of the manual in addition to the omission of certain appendices is that it seems rather difficult to determine which species of timbers are important in Malaya without reading every description in two volumes; a time-consuming process.

It seems advisable to note that the price of these books as given is somewhat misleading. Prices quoted are in Straits dollars which are roughly equivalent to 1/3 of the U.S. dollar.

Unquestionably this manual adds measurably to the information on world timbers and, in all probability, it will serve as the reference work on Malayan timbers for some time to come.

Translocation of Ammate

BY

KENNETH L. CARVELL

ALTHOUGH much has been learned about the movement of the auxin-like herbicides in plants (2,4-D, etc.), up to the present time no literature has been published on the translocation of ammonium sulfamate. If information concerning the internal movement of this poison could be obtained, it might be possible to apply the chemical to trees in a more effective manner. In addition, specific information concerning the accumulation of the compound within the plant tissues might give some insight into the method by which this poison works.

This study was designed to obtain some of these basic data. Ammonium sulfamate does not stain the tissues through which it moves, consequently, its movement could not be followed even qualitatively by ocular examination of sectioned material. Since ammonium sulfamate can be synthesized by ordinary laboratory methods, labeling with radioactive sulfur seemed to be the ideal way to study this problem.

Synthesis of Ammonium Sulfamate

To prepare radioactive crystals of ammonium sulfamate, 5 millicuries of radioactive sulfur-35 were obtained in the form of sulfuric acid. The nucleus of this atom emits negative beta particles, and possesses a half-life of 87.1 days. Because of the relatively long half-life, it was possible to synthesize crystals and use them in various experiments over a period of many months.

Rate of Movement

Nuts of mockernut hickory (*Carya tomentosa* Nutt.) were planted in separate pots in the greenhouse. Four months after germination the seedlings were approximately 8 inches tall and contained 7 to 12 leaflets each, located near the stem tip. To determine the rate at which ammonium sulfamate is translocated, the seedlings were divided into four groups.

In three groups frills were made 2 inches above the ground level and radioactive ammonium sulfamate was applied to the exposed wood surface. The three groups of seedlings were left for 1, 3 and 24 hours, respectively, before the plants were removed from the pots and dried. The fourth group of seedlings was used as a control and no radioactive chemical was applied to the stem.

During the experiment the seedlings were exposed to full sunlight and the transpiration rate was high. The seedlings were kept well-watered.

In preparation for making autoradiograms, the dried seedlings were mounted on sheets of 10-by-12-inch blotter paper and covered with cellophane. Each mounted seedling was then placed in direct contact with a sheet of 10-by-12-inch X-ray film. The films were exposed for a period of 5 months, and were then developed. Meas-

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urements made on the autoradiograms are summarized below.

Time Interval	Upward Movement	Downward Movement
	Inches	Inches
1 hour	1.00	0.25
3 hours	3.00	0.75
24 hours	5.00	2.00

The data indicate that ammonium sulfamate moves upward more rapidly than it moves downward. This information agrees with field observations, since leaves frequently become mottled, shrivel and fall within 3 days following poisoning with Ammate. On the other hand, field experience has indicated that Ammate moves into the roots more slowly, since the chemical produces a greater root kill when applied near the base of the tree.

Method of Translocation

A second study was undertaken to determine whether ammonium sulfamate moves in the xylem or the phloem in young plants of privet (*Ligustrum vulgare* L.). The seedlings were approximately 2 feet in height, and had been raised in pots in the greenhouse. Originally, each seedling had approximately 30 leaves. For the experiment, all but the 10 topmost leaves were removed to concentrate the radioactive material in as small an area as possible.

The first phase of the experiment involved 16 seedlings, divided into four groups of four seedlings each. Frills were made 8 inches above the ground level on 3 groups of plants. A half-inch girdle was made 2 inches above the frill on one group of plants, 2 inches below the girdle on the second group, and the third group was left ungirdled. The fourth group was neither girdled nor frilled.

The frill was carefully made with a knife; it penetrated the phloem and cambium and into the xylem. In order to allow poison to be introduced into the stem over a period of 3 days, a rubber cap was placed around the frill. The base of the cup was flush with the frill and when the radioactive ammonium sulfamate solution was placed in the cup, the frill was completely surrounded with solution.

After the seedlings had been frilled and exposed to poison for a period of 3 days, the cups were removed and the leaves from each seedlings were pressed and dried. Two grams of dried leaf material from each seedling were ashed. The residues were then dissolved in sulfuric acid, and transferred to counting cups. The amount of radioactivity for each plant was determined by means of a Geiger counter, and the counts per minute for the four plants within each treatment were averaged. The logarithm of the average Geiger counter readings per minute for each treatment is as follows:

Treatment Number				
1	2	3	4	
Girdle Above Frill	Girdle Below Frill	No Girdle	Control	Standard Error of the Mean
1.4467	1.5066	1.4900	0.0000	0.0790

An analysis indicates that the amount of radioactive material in the leaves from treated plants is significantly higher than that of the control. No difference in the radioactivity between the three treatments is evident, indicating that similar amounts of radioactive material had been transported to the leaves. Since the phloem was obstructed by the girdle in Treatment 1, it is evident that the ammonium sulfamate moved upward in the xylem.

The root system of one seedling from each treatment was ashed, and the residue was dissolved in sulfuric acid. When the material was tested for radioactivity with a Geiger counter, the roots of the treated plants showed the same count as the roots of the control. Apparently no measurable quantity of ammonium sulfamate had moved down into the root system during the 3-day period. The slow downward movement agrees with the results obtained from the autoradiograms.

In the second phase of the study three privet seedlings were obtained which were forked at the base. Each seedling was ap-

proximately 2 feet in height. Originally, each of the two stems of each seedling had approximately 25 leaves, but the number was reduced to eight to restrict the area through which the radioactive material could move. Two different treatments were used. One treatment was applied to each seedling, and the third seedling was used as a control. In Treatment 1 a frill was made on one stem of the seedling, 8 inches above the fork. Two inches below this frill a half-inch girdle was made which completely removed the phloem and cambium. The other stem of the seedling was not girdled or frilled. In Treatment 2 a frill was made on one stem of the seedling, 8 inches above the fork. The other stem of the seedling was not frilled, and no girdle was made on either stem. The third seedling was neither frilled nor girdled.

After the seedlings had been frilled and exposed to ammonium sulfamate for a period of 3 days, the cups were removed, and the leaves borne on the unfrilled stem of each seedling were pressed and dried. One gram of dried leaf material from each treatment was ashed. The residues were dissolved in 2 milliliters of sulfuric acid, the solution was transferred to counting cups, and the amount of radioactivity was determined by means of a Geiger counter. Table 2 gives the average Geiger counter readings per minute for each treatment. Since no replications were made, it was not possible to compute the standard error of the mean. The logarithm of the average Geiger counter readings for each treatment is given below:

Treatment Number		
1	2	3
Girdle Below Frill	No Girdle	Control
0.0295	0.2378	0.0000

The readings from the Geiger counter indicate that the radiation emitted from the leaf residue of seedling 2 was much higher than that from seedlings 1 and 3, indicating that the girdle had restricted the movement of the radioactive material. Since the xylem was intact in each seedling, it may be assumed that ammonium sulfamate moves downward in the phloem.

Conclusions

Ammonium sulfamate moves up into the leaves more rapidly than it moves down into the root system. Since it appears to move upward in the xylem, the rate of movement is probably directly related to the rate of translocation of water in the xylem. Ammonium sulfamate appears to move downward in the phloem.

It seems probable that the upward movement of ammonium sulfamate would take place more quickly when the translocation of water in the xylem is most rapid as on warm sunny days with low relative humidity when the plant is in full leaf. Conversely, ammonium sulfamate would move upward very slowly when the transpiration rate is low. If this is true, the greater effectiveness of Ammate when applied in the early spring could be explained by the low rate of movement in the xylem, and the greater opportunity afforded for the chemical to move downward through the phloem and into the root system. It is possible that much of the Ammate which is applied in the summer is quickly transported to the leaves. When the leaves shrivel and fall prematurely, much of the chemical may be lost.

Ammonium sulfamate moves into the root system very slowly, a fact which may well explain the greater effectiveness of Ammate when applied to cups at the root collar.

The manner in which ammonium sulfamate kills plant tissue could not be determined in this study. The autoradiograms did not indicate that the chemical accumulated in any particular tissue. More research is needed before the behavior and effect of ammonium sulfamate is thoroughly understood.

The author is indebted to Dr. P. J. Kramer of Duke University, Durham, North Carolina, for help in planning the study and for reading the manuscript.

Effect of Burning on Certain Forest Soils of Northern Arizona

BY

W. H. FULLER
STANTON SHANNON
P. S. BURGESS

PRESCRIBED or controlled burning in the forests of Arizona is being investigated by the U. S. Forest Service and the Bureau of Indian Affairs as an economical method for fuel reduction in the interest of fire prevention.

Weaver (1952) reported that prescribed burning in the ponderosa pine stands of the White Mountains of east-central Arizona begun in 1948, has produced results of sufficient significance to warrant extensive study. Fire hazard, for example, was found to be markedly reduced during the year following prescribed burning.

The manner of conducting controlled burning varies somewhat with the nature of the area and the character of the vegetation. The basic principles involved, however, are similar for all areas. Burnings usually are made during the time of year when air temperatures are low and air humidity higher than usual. Fires are often set following a rain when the soil is wet or damp. Roads and natural barriers such as streams and rimrock are used whenever possible to prevent the fires from escaping. Fire strips are set against the direction of the prevailing winds.

Controlled burning is conducted in such a manner that denuding the soil of the organic or "duff"[1] layer is kept at a minimum. Uncontrolled burning, on the other hand, usually is characterized by such high temperatures that the duff layer is completely consumed and the mineral soil is exposed to climatic elements that contribute to accelerated erosion.

Reestablishment of many species of conifers is difficult on severely burned areas. The lack of adequate protection from adverse weather conditions and changes in the physical properties of the soil are believed to be mainly responsible for this condition (Fritz, 1931; Isaac, 1930; Pearson, 1923; Sproat, 1930). High temperatures during burning presumably influence the soil micro-flora. The nature of these changes is not known. The influence of uncontrolled burning on the fertility status of soils has received attention by some investigators (Alway and Rost, 1928; Burns, 1952; Fowells and Stephenson, 1934; Green, 1953; Lemon, 1946). The data,

[1]Duff is defined in this paper as forest litter and other organic debris in various stages of decomposition, on top of the mineral soil.

Arizona Agrictultural Experiment Station Technical Paper No. 338. Contribution from the Department of Agricultural Chemistry and Soils, College of Agriculture, University of Arizona. Fuller is Associate Biochemist; Shannon is a former graduate student; and Burgess is Associate Agricultural Chemist. Assistance in the collection of soil samples by members of the former Southwestern Forest and Range Experiment Station and National Forest Administration of the U. S. Forest Service is gratefully acknowledged.

however, are incomplete and often conflicting.

The studies reported here were undertaken to determine the chemical, physical, and microbial changes in forest soils resulting from controlled, uncontrolled and slash burning.

Methods of Analysis

Chemical. Determination of pH of the soils was made on a 1:1 soil to water paste. Organic carbon was determined by the wet oxidation method of Aldrich *et al.* (1945) and by the method of Walkley (1935) as modified by Peech *et al.* (1947). Total nitrogen analysis was made by the usual Kjeldahl method. The CO_2-extraction method suggested by McGeorge (1939) was used to evaluate available phosphorus, and colorimetric analysis was made on the extract for phosphorus (Dickman and Bray, 1940). Total phosphorus in the duff was determined by the method of Kitson and Mellon (1944). Exchangeable sodium, potassium, and calcium were extracted by leaching with normal ammonium acetate. The extracts were treated according to the procedure of Fields *et al.* (1951) and the cations determined with the use of a Beckman Model DU flame photometer. The base exchange capacity was measured by distillation of ammonia from the soils after the exchangeable bases were extracted and the excess ammonium salt washed out with 50 percent ethyl alcohol.

Physical. Degree of dispersion was measured by the procedure suggested by Volk (1937). Soils were allowed to slake in one liter glass cylinders of water shaken by end-over-end movement and set aside to stand for definite periods of time. Samples of the suspension were taken by a pipette. The percent of dispersed clay, expressed as percent of the total clay including organic matter, was called the degree of dispersion of the clay fraction of the soil. The moisture equivalent was determined by the method of Briggs and McLane (1907). Permeability measurements on the disturbed soils were made according to the method suggested by the U. S. Dept. Agric. Salinity Laboratory (Richards, 1954). Soils were compared with respect to permeability to water on a basis of values obtained at a fixed time after wetting and are reported as penetration in centimeters per hour.

Microbial. An estimate of microbial activity of the soils was made by measuring the amount of CO_2 evolved from 100 g. of soil during an incubation period of 14 days. Carbon dioxide was measured daily using the procedure of Newman and Norman (1934). The numbers of bacteria and fungi were evaluated by the usual dilution-plating technique. Thornton's standardized media (1922) and Rose Bengal agar described by Smith and Dawson (1944) were used.

Soils

Soils for this investigation were obtained from the Coconino National Forest in northern Arizona near Flagstaff. Samples were taken from five burned areas representing one uncontrolled forest fire area which is designated as *uncontrolled burn*, three prescribed burns made by the U. S. Forest Service designated as *controlled burn*, and one prescribed burn of a pile of slashings left after logging operations designated as *slash burn*. The soils were sampled at depths of 0-2 and 2-8 inches at all sites except that of the uncontrolled burn. A depth of 0-12 inches was sampled at this latter site. Unburned sites adjacent to the burned sites were sampled for comparison purposes. Each sample represented a composite of several samples taken near the same site. The duff layer also was sampled since the extent of burning of this layer was used to measure the severity of the forest fire. The "degree of burn" was classified as *none*, *light*, and *severe*, corresponding to visual observation of no burning, incomplete burning of the duff layer, and complete burning of duff with evidence of temperature effect on the mineral soil.

The soil in the area of the uncontrolled burns was severely burned and denuded of duff. Such burns are classed as severe. On the other hand, the degree of burn in the controlled burn areas, for the most part, were found to be light. Some small, severely burned spots occurred in the controlled burn areas but these were very limited in extent. Characteristics of these areas more closely resembled those of the land in uncontrolled than controlled burns. Since it was not always possible to obtain soil samples of uncontrolled burns adjacent to controlled burns, these severely burned spots were sampled as representing uncontrolled fire conditions.

The soils on all of the areas studied were derived from volcanic ash except on one severely burned spot where the soils were developed from sandstone. Rock and gravel content of the soils varied from 10 to 26 percent. Analyses were made only on material 2 mm. or less in size.

Results

Influence of fire on some chemical characteristics of soils. The chemical composition of the unburned duff layer was determined because this layer was largely responsible for the ash that was deposited on the mineral soil after burning (Table 1). The duff was almost wholly organic, ranging between 31 and 38 percent carbon, and having a C/N ratio that varied from 31 to 38. The unburned duff was acid, the pH value varying in the five locations from 4.1 to 5.9.

The only areas that could be classified as *light burns* occurred on controlled burn sites. Uncontrolled fires usually denuded the soil of duff completely in the areas examined. Duff remaining after the light burns had a higher content of nitrogen, phosphorus, sodium, potassium and calcium and a higher pH value than that of the original duff (Table 1). Light burning lowered the carbon content and C/N ratio of the duff.

Soils taken from sites of all three types of burns: uncontrolled, controlled, and slash, are shown in Table 2 to have been altered chemically as a result of burning. Severe burning raised the pH level of the surface 2 inches of soil about 1 unit. The carbon content decreased directly with severity of the burn. One of the most outstanding characteristics of the soils exposed to fire was the high CO_2-soluble phosphate content compared with that of soil in adjacent unburned areas. The exchangable bases as well as total soluble salts also were found to be higher in soils of burned than unburned areas. Chemical changes of the soil as a result of burning were far less pronounced on the light burns than on the severe burns except in one in-

Table 1. Chemical composition of the duff layer of soils of lightly burned and adjacent unburned areas.

Kind of Burn	Degree of Burn	pH	Carbon	Nitrogen	Total Phosphorus	Sodium	Potassium	Calcium	Ratio C/N
			(*percent*)	(*percent*)	(*percent*)	(*percent*)	(*percent*)	(*percent*)	
Uncontrolled	none	4.3	33	0.9	0.052	0.03	trace	0.27	36
Controlled	none	5.9	33	0.9	0.065	0.04	0.05	1.09	17
	light	7.1	20	1.2	0.088	0.08	trace	0.85	36
	none	5.8	32	1.0	0.059	0.02	trace	0.83	32
	light	6.8	29	1.2	0.088	0.09	0.12	0.96	24
	none	5.4	38	1.0	0.059	0.01	trace	0.89	38
	light	6.5	27	1.3	0.101	0.04	0.03	1.28	21
Slash pile	none	4.7	31	1.0	0.055	0.01	0.03	0.33	31

All percentages are expressed on the basis of air-dried material.

Table 2. The influence of burning on some chemical characteristics of soils from five sites representing three types of burns.

Kind of Burn	Degree of Burn	pH	Carbon	Nitrogen	CO_2-Soluble Phosphorus	Exchangeable Bases: Sodium	Exchangeable Bases: Potassium	Exchangeable Bases: Calcium	Total Soluble Salts
			(*percent*)	(*percent*)	(*ppm*)		(*m.e./100 g.*)		(*ppm*)
Uncontrolled	none	5.5	1.4	0.05	0.91	0.22	trace	2.9	130
Controlled	severe	5.6	0.9	0.08	1.53	0.22	0.21	5.1	142
	none	5.5	2.8	0.13	1.01	0.30	0.31	9.7	255
	light	6.5	2.3	0.14	3.91	0.30	0.43	13.5	355
	severe	6.6	1.4	0.17	6.36	0.35	0.51	15.6	355
	none	6.4	3.7	0.18	1.14	0.35	0.43	14.9	255
	light	6.4	3.0	0.16	1.40	0.35	0.36	12.7	310
	severe	7.1	1.3	0.09	1.80	0.35	0.64	20.7	855
	none	6.0	3.6	0.15	1.60	0.22	0.26	13.1	225
	light	6.1	1.7	0.08	3.20	0.20	0.22	15.8	240
	severe	6.9	1.2	0.24	9.20	0.22	0.59	15.9	1,680
Slash pile	none	5.9	6.0	0.31	1.60	0.30	0.97	15.1	235
	light	6.8	5.8	0.26	5.61	0.39	1.80	20.1	595

A depth of 0-2 inches was sampled in all areas except the uncontrolled burn which was sampled at a depth of 0-12 inches.

stance where a large deposit of ash was left. These chemical changes are brought about largely by the deposit of ash left after burning the original duff layer. Consequently, the degree of chemical alteration of the soil will be directly related to the extent of the burning of the duff layer.

The effect of burning on the chemical characteristics of the first foot of soil from severely burned spots differed only slightly from that of adjoining unburned areas. The downward movement of bases and phosphates from the burned duff as a result of leaching penetrated only to a depth of 8 to 12 inches. This observation is based upon a comparison of the chemical composition of soils sampled from severe natural burns and from adjoining unburned areas one, three and five years after a fire. The data are not presented here since, on burned areas, the chemical changes due to the fire on the soils below 2 inches, was the same as for those of the upper 2-inch layer until they disappeared altogether at depths ranging between 8 and 12 inches.

Influence of fire on some physical characteristics of soils. The principal influence of severe burning on the physical properties of soils was to increase the degree of dispersion and to decrease the permeability to water (Table 3). The permeability coefficient of a sandy loam from an uncontrolled burn was half as great, throughout the first 1-foot layer, as in the unburned soil. The effect of burning on permeability was greater in the first 2 inches of soil than in any other 2 -inch layer.

Controlled burning, i.e., light burn, affected the physical properties of the soil only slightly.

Influence of fire on some microbial characteristics of soils. The microbial activity of soil from burned and unburned areas was compared by measuring the amount of CO_2 evolved from soils incubated under favorable conditions of temperature and moisture. Alfalfa meal was added at a rate of one percent to a duplicate set of soils to eliminate as much as possible differences in CO_2 evolu-

tion caused by differences in native organic matter content.

The microbial activity of soils from burned areas was found to be lower than that from unburned areas regardless of the presence or absence of alfalfa meal (Table 4). On the other hand, the amount of CO_2 evolved from the surface 2-inch layer of soil from the slash pile burn was greater than that of adjacent unburned soil. The carbon content of this layer as shown in Table 2 was about the same in both the burned and unburned soil. This indicates that the effect of the fire on the soil beneath the slash pile was not great since it did not wholly burn the organic matter. The observation was made that the soil beneath the pile of slash was much more moist than in the open area.

Burned soils were found to be significantly higher in number of bacteria and lower in fungi than unburned soils as determined by the dilution-plating technique. The ratio of bacteria to fungi thus was markedly increased as a result of burning (Table 4). Uncontrolled or severe burning influenced the numbers of fungi and bacteria of the soil far more than the controlled or light burning.

An attempt was made to determine the influence of severe burning on the mycorrhizae of the soil. Small ponderosa pine trees on severely burned areas, four to five years after a forest fire, were observed to possess mycorrhizae on their roots. There appeared to be no difference in the density of mycorrhizae on pine seedlings growing on burned and unburned areas. Because of the importance of mycorrhizae in the establishment of the pine seedlings, further studies, more extensive in nature are suggested. The decrease in the number of saprophytic fungi as a result of burning suggests a similar condition involving the mycorrhizae.

Discussion

The most pronounced physical and chemical effects produced by uncontrolled burning were brought about by the destruction of the surface layer of unincorporated organic matter or duff. This layer, which consists mainly of fallen needles in various stages of decomposition, contains much of the supply of nutrient elements in forest soils.

In this work it was found that part of the

Table 3. The influence of burning on some physical characteristics of soils from five sites representing three types of burns.

Kind of Burn	Degree of Burn	Soil Texture	Moisture Equivalent	Degree of Dispersion	Permeability Coefficient
			(*percent*)	(*percent*)	(*cm./hr.*)
Uncontrolled	none	sandy loam	11	12	14.7
	severe	sandy loam	12	14	7.4
Controlled	none	silt loam	32	11	15.6
	light	silt loam	32	11	15.5
	severe	silt loam	32	13	1.0
	none	loam	35	11	19.3
	light	loam	34	16	12.9
	severe	loam	31	21	1.0
	none	sandy loam	27	12	7.7
	light	sandy loam	18	12	3.4
	severe	sandy loam	18	20	1.2
Slash pile	none	sandy loam	30	9	5.1
	light	sandy loam	33	12	3.6

A depth of 0-2 inches was sampled in all areas except the uncontrolled burn which was sampled at a depth of 0-12 inches. All percentages are expressed on the basis of air-dried soil.

nitrogen in the duff was lost by burning. The basic constituents of the duff, on the other hand, were not volatilized but concentrated. Moreover, they were changed to more soluble forms. Rains leached some of the soluble alkali salts into the mineral soil as well as into the remaining duff, causing a rise in pH value of these layers.

When the duff was not completely burned, a condition typical of much of the controlled burn area, fertility of the soil was temporarily increased. Phosphorus, particularly, was made more available. In the case of uncontrolled fires, however, the duff was completely burned down to the inorganic soil. The effect of the heat on the soil extended to a depth of 2 to 3 inches. The main effect of heating was to dehydrate the clay colloids and destroy the structure in the surface layer. The soil of these areas was no longer protected by the duff from the beating action of raindrops. It thus became dispersed and compacted. This resulted in a decrease in permeability of the soil. Water runoff and erosion were observed to be accelerated in these severely burned areas.

Summary

The chemical, physical, and microbial characteristics of forest soils from areas of uncontrolled and controlled forest fires and a slash pile burn were compared with those of adjoining soils of unburned areas. The investigation was carried out in the ponderosa pine area of northern Arizona.

The most prominent changes brought about by the fires were caused by the destruction of the surface layer of duff or unincorporated organic matter. Soluble salts derived from the ash of the duff leached into the soil causing an increase in the pH, available phosphorus, exchangeable bases, and total soluble salts and a decrease in organic matter and C/N ratio to a depth of 8 to 12 inches. Burning of the duff resulted in a greater dispersion of the surface few inches of soil and greater compaction than was found in unburned soil. Water penetration rate was reduced on burned areas. The microbiological activity of the soil decreased slightly in direct relationship with the intensity of the fire. The ratio of bacteria to fungi increased in direct relation-

Table 4. The influence of burning on the microbial activity and numbers of bacteria and fungi of soils from four sites representing three types of burns.

Kind of Burn[1]	Degree of Burn	Carbon Evolution[2] Soil Alone	Soil + Alfalfa	Numbers of[3] Bacteria	Fungi	Ratio Bact./Fungi
		(*mgm.*)	(*mgm.*)	(*10^6/g.*)	(*10^5/g.*)	
Uncontrolled	none	156	486	83	50	17
	severe	140	440	332	15	224
Controlled	none	185	560	98	39	2
	light	121	502	114	34	34
	severe	111	464	446	19	235
	none	139	506	84	32	26
	light	115	505	223	41	54
	severe	63	436	58	4	145
Slash pile	none	147	505	82	33	25
	light	181	580	108	20	54
L.S.D. 0.05		53	66	112	12	

[1]A depth of 0-2 inches was sampled in all areas except the uncontrolled burn, which was sampled at a depth of 0-12 inches.

[2]Carbon evolved as CO_2 from 100 g. of air-dried soil during 14 days' incubation; mean of triplicate determinations.

[3]Each figure represents a mean number of colonies found on 6 plates.

ship with the extent of burning of the duff layer and soil organic matter.

Controlled or prescribed burning resulted in less prominent changes in the original characteristics of the soils than uncontrolled burning by natural forest fires.

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Greenhouse Studies in Mineral Requirements of Conifers: Western red cedar

BY

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IN spite of the importance of forest products in our economy, relatively little attention has been paid to the physiology of the trees which produce these materials. Perhaps this is true because large perennial plants can not be adapted easily to experimental work, and because harvest is the most important problem in the management of mature stands of timber. The advent of tree farming has made the production of seedlings for planting more important, and has stimulated interest in any manipulation which may increase the growth rate of natural regeneration or planted stock. A common reason for sub-optimal growth in young trees is a deficiency of one or more essential mineral elements. Information about the mineral requirements of tree species is needed for use in basic studies of forest soils, and for use as a guide in fertilization practice in nurseries or in forest stands.

There have been three general approaches to the problems of the mineral nutrition of forest trees. The first has been concerned with the growth survival of planting stock as affected by fertilizer practices in forest nurseries. The fertility levels of productive forest soils have been simulated in the nursery as in the studies of Wilde (1938) and of Youngberg and Austin (1954). The objective is, of course, the successful establishment of the seedling. The second tack has involved the fertilization of forest stands either to correct a recognized nutrient deficiency or to stimulate the growth rate by a general raising of the fertility level. There have been notable successes in such treatments, as exemplified by the work of Heiberg and White (1951) in correcting potassium deficiencies in pine and spruce, and the remarkable responses to zinc fertilization in certain plantations in Australia (Stoate, 1950). The established status of fertilization practice in Europe has been recently reviewed by Alten and Doehring (1952). The third approach, and the one employed in this study, is the investigation of the mineral requirements of tree species in culture solutions, sand cultures, or soil pot cultures, under greenhouse or other

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semi-controlled conditions. This type of study has the advantage of limiting the variables entering the experiments, with the results that basic information concerning the mineral requirements of particular species may be obtained. It has the disadvantage in that only seedlings or saplings may be used, leaving open the possibility that the conclusions may have limited value in assessing the needs of older trees. There is some evidence (Alten and Doehring, 1952) that high requirements for minerals may continue in conifers to an age of 20-30 years or more. The demands of seedlings, thus may give better indications of continuing needs than usually is believed to be the case.

There have been many successful attempts to grow tree seedlings in solution and sand cultures, and a review of this work has been given by Olson (1944). A thorough study of white pine in soil pot cultures and sand cultures was conducted by Mitchell (1934, 1939). Except for a brief report by the authors (Gessel *et al.*, 1951), no record of experiments with western red cedar, *Thuja plicata* Donn, has been seen, This species is an important timber tree in the Pacific Northwest, and it seemed to be a suitable plant with which to initiate this series of investigations in the mineral nutrition of the conifers. The studies have involved the growing of seedlings in solution, sand, and soil cultures in the greenhouse; followed by the determination of yields under various mineral treatments, and by chemical analysis of the resulting foliage.

Materials and Methods

Seeds were supplied through the courtesy of the Manning Seed Co., Seattle, Washington, from collections made in western Washington. They were stratified for 4 weeks at 5° C. in a peat-sand mixture, after which they were sown in a greenhouse flat containing unsterilized silica sand (20-30 mesh). The seeds were planted about 2 mm deep, at the rate of 10 g. of seed per flat 15 in. by 24 in. in size. The sand was kept moist with tap water, and the flat covered with a glass pane until the seeds germinated, an interval of about 2 weeks. The pane was then removed to lessen danger of damping off, and irrigation continued with tap water supplemented by sprinkling 2-3 times weekly with 1/4 strength nutrient solution. The seedlings were transferred to the various types of cultures 1-2 months after planting. Their shoots at this time were 3-5 cm. high, and their primary roots were still relatively un-

Table 1. Compositions of solutions used (mols/liter).

	Complete[1]	Low N	Low P	Low K	Low Ca	Low Mg	Low S
$NH_4H_2PO_4$	0.0005	0.000005	0.000005	0.0005	0.0005	0.0005	0.0005
KNO_3	.003	.....	.003	.00002	.003	.003	.003
$Ca(NO_3)_2$	.002	.000035	.002	.002	.00002	.002	.002
$MgSO_4$	.001	.001	.001	.001	.001	.00001	.000004
NaH_2PO_4	.....	.000495	.....	.....	.....	.....	.....
K_2SO_4	.....	.0015	.....	.....	.....	.....	.....
$CaCl_2$	.....	.001965	.....	.....	.....	.....	.....
NH_4Cl	.....	.....	.000495	.....	.....	.....	.....
$NaNO_3$	.....	.....	.....	.00298	.00396	.....	.....
Na_2SO_4	.....	.....	.....	.....	.....	.00099	.....
$MgCl_2$	.....	.....	.....	.....	.....	.....	.000996

Micronutrients were added as follows:

Fe (as $FeCl_3$) 0.5 ppm
B (as H_3BO_3) 0.125 ppm
Mn (as $MnCl_4$) 0.125 ppm
Cu (as $CuCl_2$) 0.005 ppm
Zn (as $ZnCl_2$) 0.0125 ppm
Mo (as Na_2MoO_4) 0.0125 ppm

pH was adjusted to 5.5 ± 0.1 at each solution change.

[1]Complete solution was used for —Fe and —B cultures, with respective micronutrient supplements omitted.

Fig. 1. Western red cedar plants growing in sand cultures, showing the method of irrigation.

branched and had not yet reached the bottom of the flat. Athough it was possible to transfer older seedlings, they became established in the cultures less readily than the smaller ones.

Preliminary experiments (Gessel *et al.*, 1951) had already shown that deficiencies of several macro-nutrients could be induced very quickly in seedlings of this species if the elements involved were omitted entirely from the nutrient medium. In the current studies the nutrients were adjusted to levels which would allow considerable growth of the young trees, but still restrict growth to some degree and cause development of deficiency symptoms. Thus, nitrogen, phosphorus, calcium, and magnesium were maintained at 1/100 of the complete level, potassium at 1/150 and sulfur at 1/250 of the complete concentration; whereas iron and boron were not added intentionally to the solutions in which they were to be deficient. The solutions and methods used were modified from Hoagland and Arnon (1938). The solution compositions are given in Table 1. Reagent grade salts were used dissolved in distilled water. Sodium and chloride salts were used to keep ions not being varied at their normal levels, and to maintain the osmotic pressures of the solutions at nearly equal values. Data which follow indicate that Na absorption was negligible.

For sand cultures, 3-gallon crocks were filled with 20-30 mesh silica sand which had been washed with dilute aqua regia and rinsed thoroughly with distilled water. Five seedlings were grown in each crock, and treatments were in quadruplicate. Irrigation with the nutrient solutions was by the drip technique described by Shive and Robbins in 1942 (Fig. 1). The solution reservoirs were 1-gallon mason jars; the crocks were fitted with drain tubes on one side near the bottom; and the used solution was collected in 1-gallon jars below. Solutions were renewed weekly, and passed through the sand 2-3 times during the week. The crocks were occasionally flushed with distilled water to eliminate possible accumulations of salts near the surface of the sand.

Solutions cultures were conducted in 23-liter stainless steel tanks equipped with covers of the same material perforated with 28 holes of 1⅜ inch diameter. Tanks and covers were coated on the inside with two coats of black asphaltum varnish and on the outside with two coats of aluminum enamel. The seedlings were supported in flat one-hole paraffin-coated corks, using non-absorbent cotton to hold the plants in place. In preliminary trials forced aeration had no beneficial effect, and it was omitted in further experiments. Iron was supplied as the chloride rather than as the tartrate because it was observed that the latter encouraged the development of fungi on the root systems. Twenty liters of solution were used in each tank; solutions were changed every two weeks; and iron was added weekly. For the first 8-12 months, 28 plants were maintained in the tanks, but they were then thinned by a partial harvest to 6-8 plants per tank. In the later stages of growth, the plants were supported by frameworks attached to the tank covers.

Soil pot cultures were conducted using the methods of Jenny *et al.* (1950). Seven-inch pots contained 2700 grams of soil, with 2 seedlings planted in each pot. Irrigation was with distilled water.

In all experiments the plants were harvested and dry weights of shoots and roots recorded, except in the case of some of the older plants from which only foliage samples were taken. The material was dried to constant weight in a ventilated oven at 70° C. Foliage samples for analysis ncluded the green, succulent young stems, but excluded the brownish, heavily lignified stems and branches. In several instances the foliage was divided into a *younger* portion of healthy or healthier green appearance, and an *older* less green or more necrotic portion. The tissue analyzed was a mixture of that obtained from all replicates, and was ground to pass a 40-mesh screen.

Table 2. Height of shoot, yield, and mineral composition of plants grown on sand cultures.[1]

Treatment	Ave. Ht. of Shoot (*cm*)	Ave. yield per crock (dry g.) Shoot	Root	Total	Mineral composition of dry foliage (m.e. per 100 g.) Ca	Mg	K	Na	SO_4	N (*percent*)	PO_4 (*percent*)	Fe (*ppm*)	B (*ppm*)
Complete	40.0	39.9	9.4	49.3	44.9	22.8	47.7	1.1	16.5	2.94	1.09	163	33
—B	38.0	34.0	7.4	41.4	45.0	20.0	51.6	0.23	.....	2.91	1.17	.....	10
—Fe	36.8	34.6	8.1	42.7	46.5	19.7	58.0	1.5	.....	2.70	1.08	274	.....
Low N	22.6	12.9	4.0	16.9	52.5	18.8	51.2	1.3	.....	1.75	0.89	.....	.....
Low P	30.1	19.1	4.5	23.6	46.0	13.3	63.3	1.0	.....	2.34	0.41	.....	.....
Low K	31.4	27.9	7.3	35.2	61.9	23.8	19.5	0.70	.....	2.54	1.10	.....	.....
Low Ca	32.9	28.3	7.8	36.1	11.2	39.2	60.3	1.7	.....	3.18	1.29	.....	.....
Low Mg	33.1	25.8	6.3	32.1	64.4	8.0	60.3	1.6	.....	2.49	1.08	.....	.....
Low S	27.7	18.6	7.2	25.8	45.4	16.1	48.8	1.5	7.3	2.87	0.96	.....	.....
Complete w/o suppl.[2]	32.5	26.4	7.8	34.2	47.1	20.8	48.7	.....	.....	2.93	1.13	.....	.....

[1]Seedlings (5.5 cm shoot) transferred to the sand 29 June 1950, and harvested after 10 months.
[2]B, Mn, Zn, Cu, and Mo omitted from the solution.

Table 3. Yields and mineral composition of plants grown in tank cultures: Experiment 10.[1]

Treatment	Harvest Date	Ave. Ht. of Shoot (*cm*)	Yield per tank (dry g.) Shoot	Root	Total	Portion of foliage	Mineral composition of dry foliage (m.e. per 100 g.) Ca	Mg	K	SO_4	N (*percent*)	PO_4 (*percent*)	Fe (*ppm*)	B (*ppm*)
Complete	May 1951	46.1	100.9	18.7	119.6	Entire	44.6	18.8	58.8	19.1	2.70	1.05	.....	66
	Dec 1951					Older	50.8	21.5	39.3	21.2	1.90	1.03	590	104
						Younger	36.9	21.7	67.7	24.7	2.66	1.38	220	32
—B	May 1951	44.7	106.3	18.3	124.6	Entire	.. ..	.. ..	.....	.....	.....	.....	.....	15
	Dec 1951					Older	48.2	23.4	45.2	.....	2.17	0.94	.....	28
						Younger	30.1	22.5	60.5	.....	2.93	1.44	.....	14
—Fe	May 1951	41.2	86.4	15.7	102.1	Entire	.. ..	.. ..	.....	.....	.....	.....	156	.....
	Dec 1951					Older	47.4	23.1	44.9	.....	1.90	1.14	600	.....
						Younger	38.6	26.4	56.5	.....	2.60	1.38	260	.....
Low N	May 1951	40.0	88.1	28.0	116.1	.. ..	.. ..	.. ..	.....	.....	.....	.....	.....	.....
	Dec 1951					Older	69.9	19.6	72.7	.....	0.70	0.66	.....	.....
						Younger	54.5	22.2	82.6	.....	0.88	0.94	.....	.....
Low P[2]	May 1951	33.8	67.1	18.0	85.1	Entire	37.9	13.1	68.0	.....	2.17	0.36	.....	.....
Low K	May 1951	42.0	97.9	17.7	115.6	.. ..	.. ..	.. ..	.....	.....	.....	.....	.....	.....
	Dec 1951					Older	73.1	33.9	7.0	.....	2.70	1.02	.....	.....
						Younger	46.1	29.0	13.8	.....	3.05	1.16	.....	.....
Low Ca	May 1951	37.8	77.0	14.5	91.5	.. ..	.. ..	.. ..	.....	.....	.....	.....	.....	.....
	Dec 1951					Older	10.4	34.4	58.8	.....	2.38	1.41	.....	.....
						Younger	4.6	30.6	78.9	.....	2.96	1.35	.....	.....
Low Mg	May 1951	43.7	109.0	17.6	126.6	.. ..	.. ..	.. ..	.....	.....	.....	.....	.....	.....
	Dec 1951					Older	55.5	3.5	66.1	.....	2.30	1.40	.....	.....
						Younger	37.5	8.2	96.2	.. ..	3.00	1.60	.....	.....
Low S	May 1951	43.4	107.9	19.9	127.8	Entire	.....	.....	.....	7.78	.....	.....	.....	.....
	Dec 1951					Older	55.2	18.4	48.9	18.9	2.86	0.92	.....	.....
						Younger	41.7	19.2	82.1	19.1	3.01	1.37	.....	.....

[1]Twenty-eight seedlings (6 cm shoot) transferred to each tank 2 August 1950. A partial harvest of 20 seedlings from each tank was made 21 May 1951. The remaining plants were continued until 29 Nov 1951, at which time they were harvested and the foliage divided into older and younger portions for chemical analysis.
[2]An error in solution composition after the May 1951 harvest vitiated further results with the Low P culture.

Experimental Results

Seedlings were transferred to the sand cultures in June 1950 and were harvested in April 1951. Strong evidence of mineral deficiency had developed by the latter date in all cultures except *low potassium*, *minus iron*, and *minus boron*, but even in these exceptions the yields were obviously reduced. The heights of the shoots, the yields in dry tissue, and the mineral compositions of the plants are given in Table 2. As would be expected, reductions in yields were accompanied in all cases by lower contents in the foliage of the respective deficient elements. Sodium uptake was negligible, even though the sodium content of some of the solutions was necessarily high.

Two principal experiments were conducted in tank cultures. The first of these, Experiment 10, was started in August 1950, and continued with 28 plants per tank until the following spring. During the fall and winter seasons the rate of growth was low, and acute deficiency symptoms did not develop. In the spring the growth rate increased. Soon, obvious symptoms were visible in all cultures except *minus iron*, *minus boron*, *low potassium* and *low sulfur*. In May, twenty plants were harvested from each tank, with the remaining 8 plants being maintained for further study. Under the influence of the summer growing conditions, deficiencies of all elements became obvious although boron deficiency was noted only in the roots. The remaining trees were harvested in November 1951, and the foliage separated into older and younger portions for analyses. The seedlings were very uniform during the early stages of development in the tanks. Since they later crowded each other and were less uniform, yield data are included only for the May harvest. Deficiency symptoms were more pronounced by November, so that most of the analyses presented are of tissue collected at the final harvest (Table 3).

In view of the results of Experiment 10, it was thought probable that more critical deficiencies of boron, iron, sulfur, and potassium could be induced by starting plants in the spring so that the growth rate would be more rapid during early development. Experiment 27 was, therefore, started in April 1952, and, as was expected, the growth rate was very rapid. Deficiency symptoms were evident in all tanks by November 1952. At this time 22 of the 28 plants from each tank were harvested. The yields and mineral contents of the foliage are given in Table 4, and the appearance of representative plants is shown in Figure 2. Six plants were retained in each tank and observed until April 1954, when they were two years old. Deficiency symptoms became increasingly severe with age in all cultures except the low sulfur treatment. The low sulfur plants were somewhat smaller than those in the *complete* tank and had a yellowish cast in the foliage, but made much better growth than any other plants subjected to deficiency treatments. At the age of 2 years, the plants in the complete solution had reached a height of 4½ feet and had trunk diameters of about 1 inch (Fig. 3).

Limited tests were made in the greenhouse of the responses of western red cedar to forest soils treated with different fertilizer applications. Representative of these is an experiment in which the surface layer of a residual stony loam collected at Pack Forest, La Grande, Washington, was used. In the field this soil supports a stand of

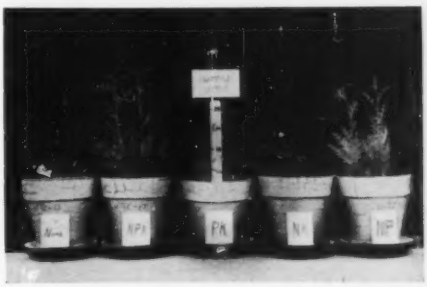

Fig. 2. Tank cultures showing the appearance of complete (left) and low nitrogen treatments at the age of 7½ months (Exp. 27). The scale gives the height of the trees in cm.

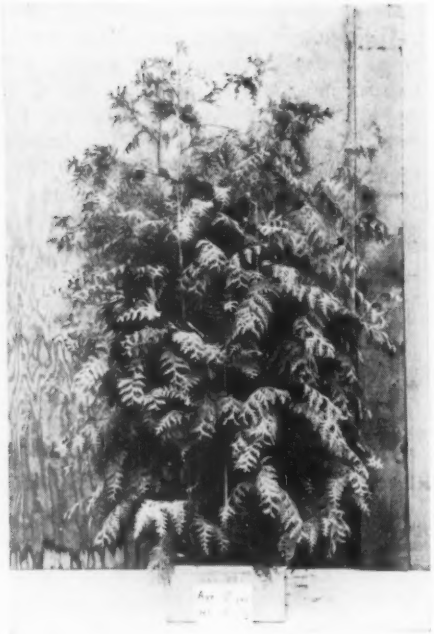

Fig. 3. Plants grown for two years in complete solution. Height 4½ ft. (115 cm.). Figure 2 shows the appearance of these same plants at the age of 7½ months.

chlorotic Douglas-fir saplings, has a history of forest fires, and shows low productivity. Samples of this soil (Lab. No. 74) had been used previously in a fertility test with Romaine lettuce, in which it was proved to be low in available nitrogen and phosphorus (Gessel *et al.* 1951). Although good responses of western red cedar to nitrogen and phosphorus applications were noted, growth was not so rapid as that obtained in tank or sand cultures (Fig. 4). This was caused at least in part by the fact that all plants (except series D) appeared to be deficient in nitrogen for some months before harvest, an observation which is confirmed by the nitrogen contents of the foliage (Table 5).

From the results of the experiments described it is seen that western red cedar has substantial requirements for the macro- and micro-nutrients tested. Descriptions of the deficiency symptoms in western red cedar for the elements included in this study are given in Table 6. In most cases these symptoms resemble those that have been described for agricultural plants (Bear *et al.*, 1949). Plants which show deficiency symptoms of a particular element are presumed to contain inadequate amounts of this ele- in their foliage. It thus becomes of interest to know what concentrations of the various elements in foliage are associated with deficiency symptoms. Such values representing ranges or averages from the experiments of this study are included in Table 6.

Discussion

The growing of trees in the greenhouse gives rise to a number of special problems. Whereas the growth period for annual plants seldom exceeds 6 months and is often much shorter, tree species must be cultured for longer periods. This means that even though reagent grade salts are used, the buildup from impurities of elements such as boron may be considerable during 1-2 years, thus making the demonstration of micronutrient deficiencies more difficult.

In the case of iron, characteristic deficiency symptoms developed, even though the plants must have received traces of iron from the steel tanks in spite of the asphaltum covering. The iron analyses of the foliage showed no consistent differences, however, between the complete and the iron deficient treatments. This can probably be explained either on the basis that there was appreciable surface contamination of iron on the foliage, or that there is some inactivation of iron in the chlorotic leaves, both of which phenomena have been observed in studies of iron in agricultural plants (Bennett, 1945).

In the conduct of soil pot cultures over extended periods in the greenhouse, it appears that it would be desirable to plan on frequent additions of fertilizers, especially nitrogen, to replace the losses from leaching, plant absorption, and possible microbiological activities. It is believed that such practice would bring the growth rates in soil cul-

tures nearer to those in solution or sand cultures. It was not feasible in this study to consider possible mycorrhizal influences in nutrition, even though this could be important in soil cultures.

Although herbaceous species have been used in most studies of mineral requirements because of their rapid development, western red cedar showed a rapid rate of growth in these experiments and required a relatively short time for the appearance of deficiency symptoms. It was interesting to observe that growth rates under artificial conditions much exceeded those noted for this species in field environments. Although a number of factors are doubtless responsible for the lower growth rates in the field, it appears likely that inadequate mineral nutrition is a major factor, perhaps even in productive soils. There is good reason to believe that fertilization of tree seedlings (and probably older trees as well) in the field would result in increased growth rates under most conditions. Such treatments may be economically feasible only under special circumstances, however.

These experiments are not sufficiently detailed to give an exact range of the content of each particular element in the plant tissue which would be adequate, minimal, and inadequate for good growth. However,

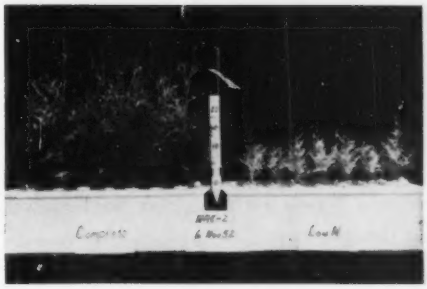

Fig. 4. Plants grown for 15 months in pot cultures on soil 74. Left to Right: Treatments A, B, C, D, and E (cf. Table 5).

the supplies of the nutrients in the medium were adjusted to give appreciable growth of the plants even though deficiencies were induced, so it is believed that the levels observed in the deficient plant tissue can be considered to represent minimal or inadequate amounts. Of course the deficiency of each element was produced in the presence of an adequate or near optimum level of all other essential elements, and it is likely that the value considered minimal or inadequate for an element might change to a lower figure if certain other essential elements were present in smaller amounts. For example the required amount of magnesium might be lower if calcium and potassium

Table 4. Yields and mineral composition of plants grown in tank cultures: Experiment 27.[1]

Treatment	Yield per tank (dry g.)			Mineral composition of dry foliage (m.e. per 100 g.)					N (per cent)	PO_4 (per cent)	Fe (ppm)	B (ppm)
	Shoot	Root	Total	Ca	Mg	K	Na	SO_4				
Complete	71.5	19.0	90.5	52.0	19.2	46.3	....	20.7	2.64	1.23	325	90
—B	62.7	17.1	79.8	47.2	20.6	44.5	....	....	2.65	1.27	....	12
—Fe	51.8	15.8	67.6	47.2	19.7	58.6	....	....	2.73	1.31	304	....
Low N	11.8	10.8	22.6	72.0	25.3	61.2	....	....	1.54	0.81	....	....
Low P	30.3	13.7	44.0	51.5	16.9	43.5	....	....	2.67	0.36	....	....
Low K	43.2	11.6	54.8	62.0	27.4	9.1	0.37	....	3.07	1.37	....	....
Low Ca	38.5	12.5	51.0	9.5	37.8	59.1	0.44	....	3.18	1.44	....	....
Low Mg	62.9	17.1	80.0	52.5	13.2	48.6	....	....	2.68	1.32	....	....
Low S	49.6	16.5	66.1	48.8	17.8	44.8	....	11.1	2.76	1.22	....	....

[1]Twenty-eight seedlings (4 cm shoot) transferred to each tank 20 April 1952. Twenty-two plants were harvested from each tank on 24 November 1952, and the above data were obtained. Six plants were retained in each tank for further observation during the next year.

were maintained at lower concentrations and absorbed in smaller amounts by the plant. Nevertheless it is believed that the values recorded give a good indication of the mineral requirements of western red cedar, and it is obvious that forest soils must supply substantial amounts of all the elements studied if they are to support good growth of this species.

There is a good possibility that trees in the field which exhibit chlorotic foliage, premature dying of foliage, or related symptoms may be suffering from specific mineral deficiencies. It should be possible to correlate these symptoms and the mineral contents of such foliage with the observations and analyses obtained in greenhouse experiments, and thus predict the fertilizer elements to which response might be expected in the field. Such correlations are expected to be the subject of a future investigation.

Summary

Seedlings of western red cedar, *Thuja plicata*, were grown in the greenhouse in sand and solution cultures in which the treatments included *complete, minus Fe, minus B, low N, low P, low K, low Ca, low Mg,* and *low S.* Young trees were grown also in pot cultures on forest soils to which various fertilizer additions were made. The periods of growth ranged from 6-24 months. Yields were recorded and chemical analyses performed on the foliage harvested from each experiment. The principal results were as follows:

1) The trees made excellent growth in culture solutions and sand cultures, reaching a height of 4½ feet in some instances. Growth was slower in soil cultures, probably because of the leaching out of soluble nitrogen in the greenhouse watering.
2) Characteristic deficiency symptoms were observed for each of the elements studied and these are described in detail.
3) The chemical analyses make possible a comparison of the levels of the various elements found in normal foliage with those in deficient foliage.
4) Definite responses to N and P fertilization were observed in the pot culture experiments.

Some applications of experiments of this type to the production of trees in the field are discussed.

Table 5. Yield and composition of foliage plants grown in pot cultures on soil 74.[1]

Treatment	Ave. yield per (dry g.) Shoot	Root	Mineral composition of dry foliage (m.e. per 100 g.) Total	Ca	Mg	K	N (*percent*)	PO_4 (*percent*)
A. None	0.64	0.74	1.38	----	----	----	1.19	----
B. $N_2P_4K_1$[2]	6.56	7.18	13.74	61.1	18.8	30.7	0.90	0.52
C. $N_0P_4K_1$	0.96	1.00	1.96	----	----	----	1.12	----
D. $N_2P_0K_1$	3.9	1.58	5.48	50.0	18.4	23.8	2.40	0.28
E. $N_2P_4K_0$	5.88	5.20	11.08	61.5	17.2	31.6	0.94	0.51
F. $N_2P_6K_1$	6.10	6.18	12.28	59.9	18.3	36.6	1.00	0.54
G. $N_2P_4K_1$ Lime[3]	6.24	5.18	11.42	69.3	13.3	28.8	1.03	0.50
H. $N_2P_4K_1B$[4]	6.02	5.36	11.38	58.6	16.9	33.0	0.98	0.52

[1]Two plants per 7" pot started 29 August 1950 and harvested 7 December 1951. Treatment were run in quadruplicate.

[2]Subscripts refer to the rate of application in hundreds of pounds per acre of N, P_2O_5, or K_2O.

[3]Calcium carbonate, equivalent to 2 tons per acre.

[4]H_3BO_3 equivalent to 3.5 pounds B per acre.

Table 6. Mineral deficiency symptoms of western red cedar as observed in solution, sand, and soil cultures.

Element	Deficiency level[1]	
Boron	15 ppm	Elongation in growing regions much restricted, so that the needles are closely bunched, approaching the "rosette" in angiosperms; stems weak, so that upper parts of plant lop over; older foliage near normal; younger foliage becoming "bronzed" in advanced stages; roots short, with the branches somewhat bulbous on the ends.
Iron	———	Youngest foliage quite yellow; older foliage green. This difference was more striking as the plants became older.
Nitrogen	<1.5%	Foliage very yellowish; stems reddish in young seedlings; dying of older foliage conspicuous, but little shattering noted; roots abnormally long in solution cultures; foliage sparse.
Phosphorus	0.4% (PO_4)	Stems and older foliage reddish or purplish during the first year, turning to a reddish brown and becoming necrotic in older seedlings; oldest foliage dies but does not shatter. Youngest foliage retains good green color.
Potassium	10-20 m.e.	Stems limber, causing a drooping appearance in the foliage; foliage sparse, apparently because fourth order branches do not elongate; foliage at the tips of the branches remaining a good green in color, but older foliage necrotic or dying, with many of the lower leaves and branches dead and brown.
Calcium	5-10 m.e.	Browning and dying at the tips of the leader and branch shoots; good green color maintained in lower foliage; in solution cultures browning and dying of roots obvious.
Magnesium	5-15 m.e.	Plants made good growth in height, and the youngest foliage remained green, but the older branchlets turned yellow or white then became brown and showed a marked tendency to shatter. This resulted in plants with a tuft of green at the top, but with bare branches below. Other deficiencies do not seem to produce the white or yellow stage in necrosis which is characteristic of magnesium.
Sulfur	5-10 m.e.	Foliage becomes yellowish, this being more apparent in the younger portions. In iron deficiency the older foliage remains a good green color, whereas in sulfur deficiency the older foliage is paler than normal, although not so yellowish as the younger portions of the plants. In dealing with both sulfur and iron deficiencies it must be remembered that all yocng growth tends to be yellowish for a time, especially during the seasons in which weather conditions are favorable for rapid growth.

[1]These studies were not sufficiently detailed to establish critically the required levels of the various nutrients. The quantities given (in % or m.e. per 100 dry g.) were the levels found in deficient foliage.

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Effect of Deer Browsing on Quality of Hardwood Timber in Northern Michigan

BY

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THE EFFECT of browsing by whitetail deer on hardwood reproduction has received considerable attention in the Lake States during recent years. The concern has been largely with the influence browsing has had on the quantity of reproduction, with little reference to its effect on the quality of the surviving stems.

Several studies have shown that reproduction in the northern hardwood type may be adversely affected by excessive browsing. DeBoer (1947) in Wisconsin pointed out that heavy browsing by deer resulted in considerable loss of reproduction. He added that although 67 percent of hard maple stems were hard hit one year the stocking averaged *about 1600 stems per acre, and would, even if all heavily browsed specimens were to leave the stand, still have some 528 stems per acre (acceptable stocking under maturing stands). Although this gives some assurance of restocking for this species, it must be remembered that, with the depletion of other non-commercial species of high palatability, the heavy browse rate will probably go even higher and a year or two may result in a far less desirable picture.* Graham (1954) has shown after many years of investigation in the Upper Peninsula of Michigan that deer have a profound effect on their own environment by excessive browsing. At the same time he stated that *From the viewpoint of forest reproduction the situation though not ideal is in most places not actually disastrous.* In a study of deer damage to reproduction in both upland and swamp types in the Argonne Experimental Forest in Wisconsin, Arbogast and Heinselman (1950) placed 96.4 percent of their 648 study plots in the *Heavy* and *Very Heavy* browse damage classes, a condition which they emphasized is silviculturally undesirable.

From the above studies it is evident that severe browsing by deer may limit the number of trees that grow successfully to produce a merchantable stand. Graham's work also has demonstrated that species composition is rendered somewhat less desirable both for deer food and cover and for timber production, as the growth of hemlock, cedar, and yellow birch is curtailed in favor of hard maple and balsam fir. The latter species tend to become dominant after many years of browsing. But, assuming that a well-stocked stand of maple finally escapes, does the excessive browsing that may have eliminated some of the other valuable timber trees actually cut down the dollars and cents profit to the logging op-

A contribution from Pittman-Robertson Project 70-R, Game Division, Michigan Department of Conservation. Switzenberg is in charge, Cusino Wildlife Experiment Station, Michigan Deaprtment of Conservation, Shingleton, Mich.; Nelson is Research Forester, Coweeta Hydrologic Laboratory, U. S. Forest Service, Dillard, Georgia; Jenkins is Cover Management Specialist, Michigan Department of Conservation, Lansing, Mich.

erator through any secondary effects of browsing on the quality of the logs themselves? That is the question we are primarily concerned with in this paper. Specifically, the overall objective of this study was to determine the influence which deformities caused by deer browsing may ultimately have on the quality and quantity of merchantable timber. The study was focused on three major questions:

1. Can northern hardwoods reproduce adequately under severe browsing by deer to produce a satisfactorily-stocked merchantable stand?
2. What will be the quality of the resulting timber, particularly with respect to such defects as rot, crook, and catface?
3. Does browsing have an adverse effect on growth rate of the tree species involved, and if so, how much?

Description and History of Areas Studied

The area selected for study is an upland island of hardwoods located in a large coniferous swamp some thirteen miles east of Munising, Michigan. The island is approximately one mile long and three-eighths of a mile wide, or about 200 acres in extent. Its main soil type is mapped as Trenary fine sandy loam with some Ogemaw fine sandy loam and Saugatuck sand along the periphery (Veatch *et al.*, 1929). All stem samples were cut in the Trenary fine sandy loam type. Dominant hardwood species at present consist largely of hard or sugar maple (*Acer saccharum* Marsh.), American elm (*Ulmus americana* L.) and black cherry (*Prunus serotina* Ehrh.). Stem size varied from 1 to 8 inches d.b.h., with the preponderance of the stems in the 2-5 inch class. Number of stems counted per acre and basal area calculations on the total stems present indicated adequate stocking.

The area has been heavily used by deer in the past. Much of the logging of hardwood timber in this part of the country occurred during and after World War I (1915-1930). Deer increased in numbers as food conditions improved following cutting. They undoubtedly yarded in the swamp and on this island of virgin hardwood for many years before logging operations began, browsing and rebrowsing the tolerant hard maple reproduction that persisted under the dense shade. In 1922 the timber was clearcut. Abundant reproduction of the hard maple promptly followed, which was utilized by the large numbers of deer that came to the island each winter. It has been estimated by various Michigan game technicians that several hundred deer fed here annually.

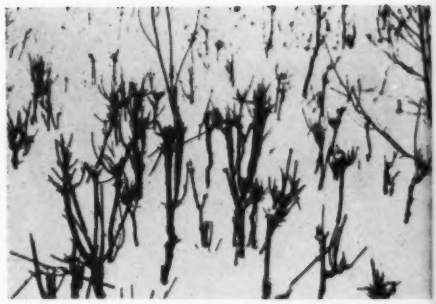

Fig. 1. Effect of severe browsing by deer on hard maple. 1928 photograph.

In 1928, Michigan Land Economic Survey workers found dense hardwood reproduction not yet of sufficient height to be included in the 0-1 inch d.b.h. class. Obviously, deer had kept most of it in this size class during the six years since cutting. I. H. Bartlett of the Michigan Department of Conservation took a picture (Fig. 1) to show the effect of severe deer browsing. Bartlett revisited the area nine years later (1937), and found that most of the reproduction had escaped the deer (Fig. 2). Cut samples (Fig. 3) indicated that the escape occurred in 1931 or 1932. For a period of approximately ten years, therefore, between 1922 when it was clearcut and 1932 when it escaped, this reproduction was annually subjected to the severest kind of deer browsing.

Fig. 2. Same area as shown in Figure 1. Escape from deer browsing occurred about 1932. 1937 photograph.

The relatively unbrowsed stand selected for the control is located about five and a half miles south of the island study area. It is within one-half mile of the extreme southern boundary of the conifer swamp which encloses the hardwood island. Its soil type is the same as that of the island, namely Trenary fine sandy loam. Although somewhat different in quantity of stems, the two areas are very similar in species composition and age classes. Sapling and pole stages (1-8 inches d.b.h.) predominate in both stands, with the majority of stems in the 2-5 inch class.

A detailed history of the control area is not available, but interviews with local inhabitants who had spent a large part of their lives in the immediate vicinity, disclosed that this stand of timber has been subjected to a negligible amount of deer browsing as compared with the study area. Observations as far back as 1923 indicate that not more than ten deer used the area annually, and then only when entering or leaving the winter deeryard to the north. Periodic inspections of the stand by Cusino Station personnel in 1951 and 1952 confirmed this belief, as few signs of deer were found. It is believed the area was cut about the same time as the hardwood island (1922).

Methods

In discussing the principal field procedures used in this study, the authors would like to express their appreciation to other staff members of the Cusino Wildlife Experiment Station who aided in the work, and especially to Wayne D. Burnett, then assigned to the Station, who supervised cutting operations in the control area and worked up much of the present field data. Credit also is due several members of the staff of the Lake States Forest Experiment Station, U. S. Forest Service, for technical advice on the project.

Three semi-circular 1/10-acre plots were established in each area, and a tally was made of the number of stems within each plot by species. All the stems were then cut at average snow level (2.9 feet) and again at three feet above snow level, removing for study the three-foot length of stem exhibiting the most evidence of deer browsing. Each billet or section of stem thus obtained was split longitudinally through the heartwood and numbered. Each stem was closely examined to determine its quality as a potential saw-log and what deformities may have resulted from the effects of browsing.

Classes were established as follows: (1) *entrance of rot*, which included three subclasses, *rot absent*, *rot present*, and *serious rot*; (2) *crook formation*, which included the two sub-classes, *crook present* and *crook absent*; and (3) *presence of catface*. Criteria differentiating the classes of rot were established, the primary consideration being the probable future condition of the stem. The *serious rot* classification was defined as including stems in which rot showed no signs of being arrested, in which rot was noted in the entire length of the bole, or in which the width of incipient or

advanced decay was large in comparison with the full diameter of the stem. The *rot present* classification was considered as including the gradation from any indication of advanced decay to the *serious rot* category. The *rot absent* class is self-explanatory. The *crook formation* and *presence of catface* classifications need no further clarification.

Evaluation of the cut stems was made by the authors with the assistance of F. H. Longwood, then research forester with the Upper Peninsula Experimental Forest of the Lake States Forest Experiment Station, and Gene Hesterberg, forester and faculty member of the Michigan College of Mining and Technology.

Findings

On the basis of stem examination, rot in hard maple in the heavily-browsed hardwood island was only slightly more prevalent (10 percent) than in the relatively unbrowsed control areas. As can be noted in Figure 4, rot was observed in 98.1 percent of the island stems and 88.1 per cent of the control stems. *Serious rot* was more evident on the island with 68.8 percent of the stems affected as compared with 52.5 percent in the control area. The *rot present* class included 29.3 percent of the stems in the island plots and 35.5 percent in the control plots. The *no rot* group included 1.9 percent of the stems in the island and 11.9 percent in the control. Analysis of rot data in both areas indicated there was little reproduction present that showed a total absence of rot.

Formation of crook was found in 93.3 percent of the hardwood island maple stems, but in only 67.0 percent of the control stems. Catfaces were present in only 1.3 percent of stems in the island and 3.0 percent in the control areas.

It was felt there was an insufficient sampling of the other species to provide an adequate comparison. Indications, however, were that heart rot was less prevalent in the elm and black cherry stems than in the hard maple.

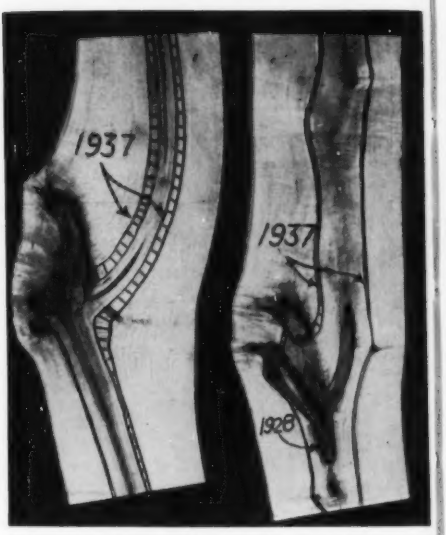

Fig. 3. Split samples confirm the history of deer browsing on hard maple. Note how corrective growth tends to straighten crook and enclose injuries. 1954 photograph.

Discussion

The conclusions to be drawn from this study, while not entirely clear in every instance, seem to show that a satisfactory stocking of hard (sugar) maple can be expected even under the severest of browsing. Since there were more than 2,000 stems per acre in the study area, over 600 of which were free of serious rot, it is evident that escape occurred and that overbrowsing did not result in an appreciable loss in the number of potentially merchantable stems.

The study further shows that entrance of heart rot in Lake Superior hardwood stands is not increased appreciably by browsing of deer. It is probable that the reproduction under study was as severely browsed as any hardwood stand could be during its initial development. Therefore, deer browsing should have produced its maximum possible damage short of total kill upon hardwood reproduction in this stand. Despite the severest kind of brows-

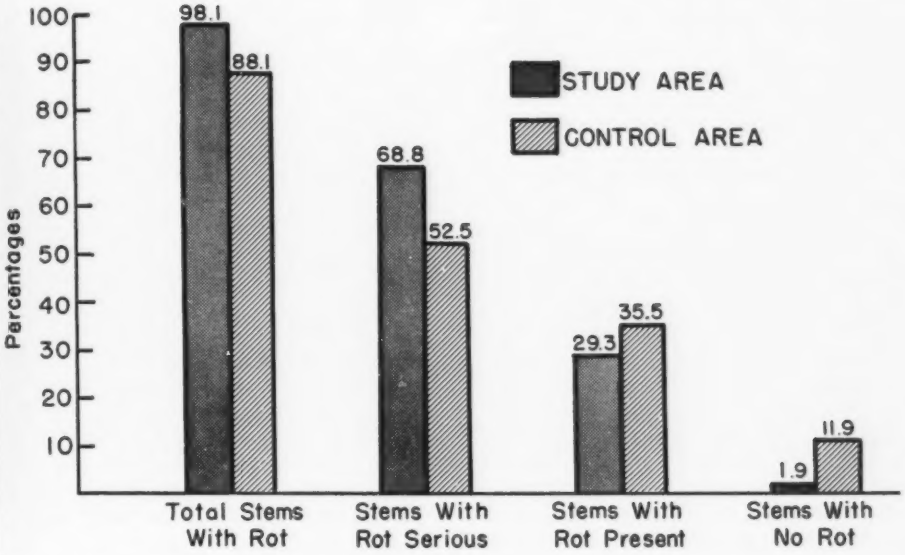

Fig. 4. Percentages of stems falling in rot classifications.

ing pressure over an extended period, the amount of rot in hardwoods found in the study area was only slightly greater than in the relatively unbrowsed control area.

Rot is normally serious in Lake Superior hardwood stands as was evidenced by Eyre and Zillgitt (1953) who state that *Old growth northern hardwood stands in the Lake States commonly contain 20 to 30 per cent defect and frequently more if trees wholly unmerchantable because of defect are included.* When the old-growth stands were getting started more than 100 years ago, deer were scarce and probably were not a causative factor.

The fact that both areas were clearcut, which would produce considerable coppice growth, probably was an important factor in encouraging rot. Some breakage undoubtedly occurs even in healthy stems from wind and ice storms, which may result in outright destruction of the tree or indirect damage from later entrance of either sap rot or heart rot. Spaulding and Bratton (1946), in describing the effects of an ice storm in New York, stated that *Much damage occurred in stands of sugar maple and beech averaging about 10-16 inches D. B. H., usually considered too small for sawlogs.* After several years they found that sap rot had gained entry into some of the damaged maples, but did not specifically report evidence of heart rot.

The above implication that deer browsing does not cause a great amount of heart rot in Lake Superior hardwoods should not be construed to mean that rot seldom occurs as a result of browsing. Cases were found in which the entrance of decay definitely could be traced to the point of browsing, although such records were not common.

The ultimate effect of decay on the final timber product is difficult to predict. At present research foresters are not in complete agreement as to the feasibility of selecting the final crop trees while the trees are in the sapling or pole stage. It is also difficult to foresee the condition of these same trees 70 to 80 years hence. Heart rot in hard maple usually is slow in advancing up or down the bole, and it is pos-

sible that rot pockets formed may become arrested so that decay does not progress further in the vigorous dominant trees which comprise the mature stand. On the other hand, many of the sub-dominant and suppressed trees would die as a result of normal competition in the development of a mature stand regardless of early rot.

The relatively high incidence of crook presents a somewhat different picture. The 26 percent higher occurrence in the hardwood island study area indicates that severe browsing by deer was a possible cause. It is felt that most of the stems that become final crop trees would outgrow the crook and the catfaces. Corrective growth was evident in the split samples (Fig. 3). There is a strong possibility, however, that a downgrading of the log might result where the crook approaches a sweep. Zillgitt and Gevorkiantz (1948) found in Minnesota that even moderate sweep can cause as much as 26 percent cull in a one-log tree. Sweep, however, was not found to be a common defect in the well-stocked stands of either area.

The fact that crook was also extensive in the control area is more difficult to explain. Possibly breakage and bending by the high winds and heavy snows so prevalent in this region may be factors.

The occurrence of catfaces may be serious if they are not outgrown in the early development of the tree. If they indicate the presence of *Nectria* sp., *Hypoxylon* sp., or other cankers which continue to develop and eventually lay the stem open to wind breakage, considerable damage and loss in volume of timber could ensue. Unless such cankers develop, however, it is believed the catfaces would not be serious enough to result in a substantial loss in merchantable wood.

The third point considered in the study was the actual amount and significance of retardation of growth which obviously occurred as a result of heavy browsing. While this was not believed to be as serious as some of the defects described above, the 10-year period during which height growth was virtually held at a standstill must be added to the length of the cutting rotation. From a purely economic standpoint, the loss from such a retardation of growth could be calculated rather simply. But areas of hardwood reproduction following clearcutting that have been held down by deer browsing for 10 years are rare and of relatively small acreage. Observations and reports of Michigan deeryard investigators during the past 25 years indicate that such heavy browsing occurs following clearcutting adjacent to deeryards, but that the reproduction usually escapes the deer by height growth in three to five years.

The effect of deer browsing on the growth of hardwood reproduction in selectively-logged stands was not a specific part of this study, but general observations and recent deer browse surveys in the western part of the Upper Peninsula indicate that browsing may be relatively more detrimental than in clearcut areas. Hemlock-hardwood stands that have had a light selective cut are attractive to deer in winter because desirable food and protection from severe weather are present in the same location. The reproduction is less abundant than in an area that has been clearcut and consequently may be subject to complete browsing and possible elimination of the desirable species.

The present study has opened up some highly interesting possibilites on the entire question of the effect of deer damage on the ultimate quality of hardwood timber in the Lake States. Although the area studied may not be typical of the greater part of the region, it is believed that the particular conditions encountered are at least common in many sections, and are especially prevalent along the Lake Superior shore of the Upper Peninsula of Michigan and in other localities in the Lake States where the hemlock-hardwood association predominates. It is realized that the work done here has only scratched the surface and that many questions still remain unanswered. We especially need to follow up on the pathology of the defects that result where deer brows-

ing is extremely severe. Such studies should be made in other areas of northern hardwoods, as for example on sites favorable to basswood and yellow birch, which were never abundant on the area studied. Certainly, similar investigations might be worth while in parts of Wisconsin and Minnesota which also have a critical deer problem.

The study strongly indicates that overbrowsing of hardwood types by deer may not be as serious as many have claimed, and that although some losses may result directly from too much deer activity, the overall loss in dollars and cents to the final timber crop is small as compared with the effects of the great number of other damaging and physical factors involved. This is not to say that present deer populations should not be controlled. Game men have long agreed with the foresters that for the good of both the deer and the trees, rigid herd control should be exercised in a great many parts of the Great Lakes deer range. For the most part such control is already underway but is generally being limited by public apathy and uninformed opposition rather than by a reluctance of the game man to take necessary action.

Summary and Conclusions

A study was made of a stand of northern hardwoods in the eastern end of the Upper Peninsula of Michigan that had been severely browsed by deer during its initial development. Results of the study showed that:

1. Satisfactory stocking of hard maple and some other hardwoods was possible even under extremely severe browsing.
2. Heart rot was not appreciably greater in the heavily-browsed study area than in the control area, which indicated that excessive browsing by deer is not an outstanding factor in the formation of heart rot in the locality studied.
3. Crook was about 26 percent greater in the study area, but it is believed the majority of the crook would be outgrown by the time the trees reach merchantable size. Where the crook approached a sweep, some downgrading of the log might result.
4. The catfaces that occurred were small and not very numerous in either area. They are believed to be insignificant from the standpoint of causing any great losses in merchantable timber.
5. Growth was retarded to some extent, but it is believed that the actual monetary losses involved over a long period of time would not be great.

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Sequential Sampling in Forest Insect Surveys

BY

W. E. WATERS

SEQUENTIAL ANALYSIS was first developed in 1943 for use in rapid evaluation of war research problems (Wald, 1943). First classified as Restricted, it was introduced into a large number of war plants as a basis for acceptance inspection by the Army, the Navy, and the Office of Scientific Research and Development. Its practical application to the fields of both sampling inspection and experimentation was quickly evident, and it was cleared for wider use in 1945. Wald (1945) and the Columbia University Statistical Research Group (1946) developed general formulas for the types of problems most commonly met.

The application of sequential analysis to biological problems has been somewhat limited,[1] but its possibilities are becoming evident—particularly in forestry and related fields. Sequential sampling serves to classify populations rather than to provide estimates of population parameters; so it is particularly applicable to surveys. It involves a flexible sample size in contrast to conventional sampling procedures, which usually specify a fixed number of sampling units to be examined. Units chosen at random from a sample are examined in sequence until the sample falls into one or more classes distinguished by specified limits. The items in or on each sampling unit (insects, in the case of forest-insect surveys) are either counted or simply recorded as present or absent, and just enough time is spent with each lot to label it properly.

Very logically, but rather oddly at first glance, the least work is required where population levels are either very low or very high; more sampling is required at intermediate levels. Adequate fixed-sample-size methods applied to surveys invariably result in too little time and labor spent at sampling points or lots having low populations, and too much time where populations are high. Usually the savings obtained by the sequential method are considerable, often exceeding 50 percent (Statistical Research Group, 1946 — hereafter called SRG). Even where practical limitations make it necessary to set an upper limit on sample size, sequential sampling can be used effectively and will result in substantial savings (Bliss and Calhoun, 1954).

Application to Forest Insect Surveys

Surveys are the first line of attack in minimizing losses by destructive forest insects. They enable forest entomologists to determine the current status of known pests, where and when outbreaks are going to oc-

[1]Oakland, 1950; Morgan, *et al.*, 1951; Bross, 1952; Stark, 1952; Morris, 1954.

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cur, if and where direct control measures are needed, how effective these measures have been, and where utilization cuttings are needed to prevent excessive losses (Orr, 1954).

The Forest Pest Control Act, passed by Congress in 1947, has made possible more active cooperation between the Federal Government and the states, private industry, and individual timberland owners. At the same time, however, it has placed a greater responsibility and work load on the Federal forest-insect-survey organization, already limited as to funds and manpower, for conducting surveys and lending technical advice and assistance in control projects. Improved efficiency of survey techniques is one means of better meeting this obligation, and sequential sampling can contribute much toward that end.

The sequential method is most feasible for reconnaissance surveys, whose function is to determine the extent and severity of known infestations and the need for direct control measures. For this type of survey both speed and reliability are essential. The infestation, or portions of it, is usually put into classes such as light, medium, or heavy —which purpose sequential sampling will serve most efficiently.

Also, for determining whether or not control measures are necessary, considerable time and expense can be saved if arbitrary limits are set for just two classes: "needing control" and "not needing control." These class limits, of course, must be based on a fundamental knowledge of the insect and the forest conditions present. The limits may be in terms of number of insects per sampling unit. For example, it might be judged necessary to spray against a certain defoliator when populations reach a level of 20 or more insects per branch sample, while 10 or less insects per branch would not be sufficient cause for such action.

Or the limits may be in terms of percentage of trees or area infested. It might be stated, for example, that white pine plantations having 15 percent or more trees currently damaged by the white pine weevil should be treated, while those having 10 percent weeviling or less should not. The active destructive stage of the insect may be sampled as a basis for judging the seriousness of the situation, or egg surveys may be conducted to obtain estimates of the potential degree of attack.

Similarly, the sequential method can be used for post-control appraisal purposes to quickly determine whether or not satisfactory control has been obtained and, if not, what trees or areas require re-treatment or continued surveillance. Also, as an adjunct to aerial surveys, which though much faster and more economical than ground methods still require supplemental ground information for accurate interpretation, sequential sampling will permit better and more rapid coverage of an area.

Other applications will arise as situations warrant. It is often important to know whether or not a natural control factor known to be present — a certain parasite, say — is at a level sufficient to alter the trend of an infestation. If enough is known of the parasite to specify that level, the decision will be reached most quickly and economically by sequential sampling.

It should be strongly emphasized that the sequential method, like any method of sampling, is only a tool and is, moreover, subject to error. It will make the best use of the competent observer's knowledge of an insect, the forest, and the basic dynamic relationships between them; but every sequential plan must be properly developed and applied to provide a sound basis for decisions.

Sequential Plans: Values and Errors Involved

Certain fundamental information is necessary to develop a sequential plan for sampling an insect population. First, the mathematical distribution of the insect counts (or other quantities) on the sampling unit used must be known. In certain cases this may be assumed with little chance of being wrong. Forest-insect-survey data will gen-

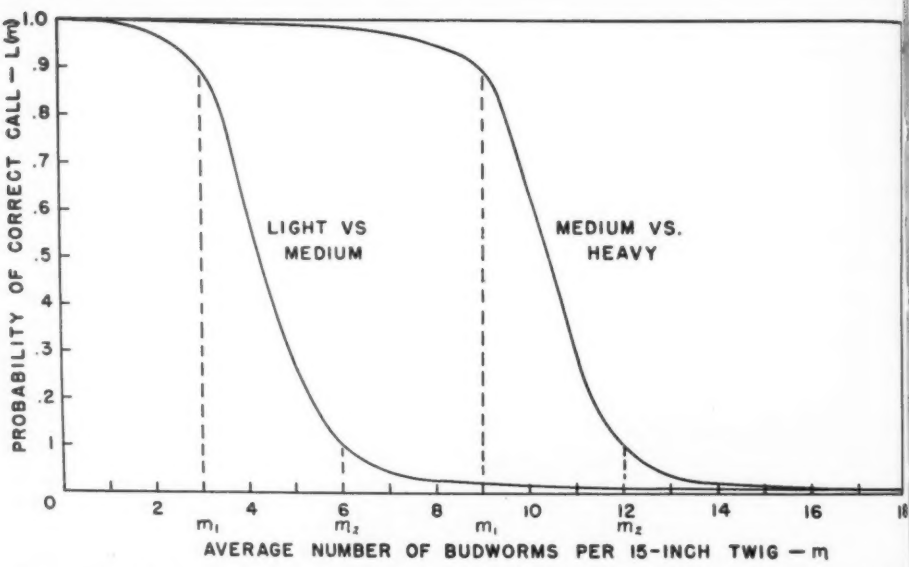


Fig. 1. Operating Characteristic curves of the sequential plan for sampling spruce budworm larval populations (4th to 6th instars) on 15-inch balsam fir twigs—90 percent confidence level.
The plotting points of L(m) and m for these curves were obtained by inserting values of a "dummy" variable x in the following formulas (Oakland, 1950):

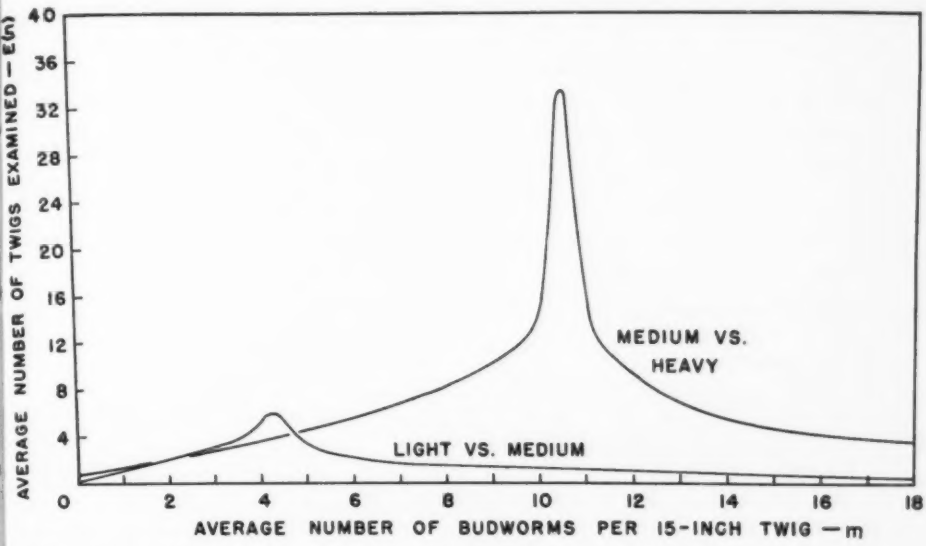
$$L(m) = \frac{A^x - 1}{A^x - B^x} \text{ where } A = \frac{1-\beta}{\alpha} \text{ and } B = \frac{\beta}{1-\alpha}$$

$$p = \frac{1 - \left(\frac{q^1}{q^2}\right)^x}{\left(\frac{p^2 q^1}{p^1 q^2}\right)^x - 1} \qquad \text{and } m = kp$$

erally fit one of the four following distributions: binomial, negative binomial, Poisson, or normal. Procedures for determining which distribution a given set of data will best fit are fully described in numerous statistical texts, such as those by Snedecor (1946) and Fisher (1948).

Next, enough must be known of the insect and the damage that it does to set class limits that have a practical meaning. The two or more classes (or hypotheses) that are to be distinguished, and their differences, must be realistic. Most commonly these are based on the causal relationship between the number of insects per sampling unit and the average amount of damage done by them. However, the tolerance limits for decisions such to spray or not to spray are based more on a judgment of maximum allowable damage and are logically influenced by economics as well as biological considerations.

Two kinds of errors are involved in sequential sampling (they are present also in conventional methods applied to similar situations, though not always recognized). There is the risk α of rejecting a hypothesis when it is true, for example, calling a light infestation medium; and the risk β of accepting it when the alternative is true;



The computed values of $L(m)$ and m are given in Table 2.

Figure 2. The Average Sample Number curves of the sequential plan for sampling spruce budworm larval populations (4th to 6th instars) on 15-inch balsam fir twigs—90 percent confidence level. The values defining these curves were computed by the following formulas (8):

$$L(m) = \frac{A^s - 1}{A^s - B^s} \text{ where } A = \frac{1 - \beta}{\alpha} \text{ and } B = \frac{\beta}{1 - \alpha}$$

$$E(n) = \frac{h_2 + (h_1 - h_2)\, L(m)}{m - b}$$

The computed values of $L(m)$ and $E(n)$ are listed in Table 2.

that is, calling a medium infestation light. The confidence levels expressed by the values assigned to these risks must be set with a practical eye to the feasibility of obtaining the specified degree of reliability and the use to which the information will be put.

Two other features of a sequential plan, the Operating Characteristic curve (OC curve) and the Average Sample Number curve (ASN curve), may be described here also. For each plan it is sometimes important to know in advance what the chances are of correctly labeling a sample or of making the correct decision as to spray or not to spray, and so forth, at the various population or infestation levels that are expected. For example, if a plan specifies that two insects or less per sampling unit constitute a light infestation and five insects or more a medium infestation, and that α and β are 0.10, then the probability of correctly calling an infestation light when there is an average of two insects per unit is 0.90 and the probability of calling it light when there are five insects per unit is 0.10. These and other probabilities of correct calls for different population levels (mean counts) or infestation percentages can be easily computed and shown graphically as an OC curve (Fig. 1).

The sampling unit and the work involved in obtaining it should be familiar to the observer. For most survey purposes the odds of 9 to 1 (α and $\beta = 0.10$) are satisfactory. On the average, then, 1 out of every

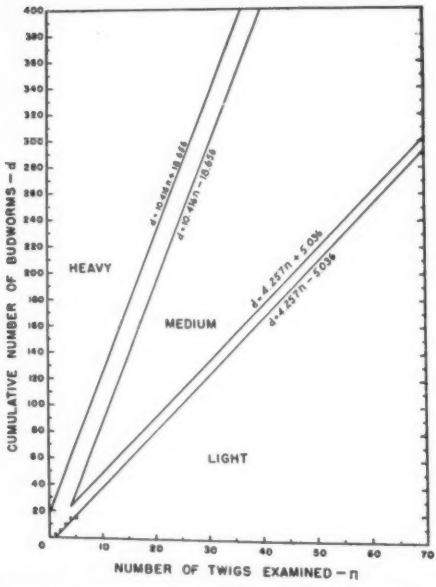


Fig. 3. Sequential graph for sampling spruce budworm larval populations (4th to 6th instars) on 15-inch balsam fir twigs—90 percent confidence level.
The small x's represent successive counts of 2, 3, 5, 4, and 1 budworm larvae. As the fifth count puts the cumulative total (15) below the decision line for LIGHT, sampling ceases and the sample is labeled LIGHT.

10 sampling points or lots may be mislabeled. The risk values for α and β need not always be equal. With some insects or under certain conditions it might be considered a more serious error to call a heavy infestation medium than to identify a medium infestation as heavy, in which case β would be set at 0.05 while α remained at 0.10. Then the chances of mislabeling a heavy infestation would be just 1 in 20. For post-control appraisals both risks should probably be set at 0.05 or lower.

Also, although the sequential method involves no fixed sample size, it is possible to calculate for each sequential plan the *average* sample size to be expected at different population levels. This can be shown graphically as the ASN curve (Fig. 2). The average sample size is directly related to the allowance or gap between classes and the desired degree of reliability. Narrowing the gap and lowering the risks of error will increase the average amount of sampling required. These factors should be weighed carefully in figuring the cost of any survey.

The curve formulas for the negative binomial distribution and the computational procedure are given in the example concerning spruce budworm populations. To avoid confusion with the general sequential formulas, however, the OC and ASN curve formulas for the other distributions are given in the Appendix.

General Formulas

Every sequential plan is defined by one or more pairs of parallel lines (Fig. 3). These lines, or values taken from them, are the criteria for distguishing between classes of infestation or for making decisions as to necessary action. A plan can be presented graphically, or for more convenient use in the field, set up in tabular form (Table 1).

The general formula for any pair of parallel decision lines is:

$$d_{1,2} = bn \pm h_{1,2}$$

where d_1 = the maximum value (s) for the lower class in terms of *cumulative* number of insects, units with insects present, or damaged trees; d_2 = the minimum value (s) for the higher class in terms of *cumulative* number of insects, etc.; n = number of sampling units examined; h_1 *and* h_2 = intercepts (where the respective lines cross the vertical axis of the graph); and b = slope of the lines.

For solving the line equations two other values, mentioned previously, are always involved but are entered in various ways depending on the distribution concerned: (1) the assigned risks, α and β, and (2) the class limits, designated hereafter as m_1 and m_2. In solving these equations m_2 must always be larger than m_1.

Also, in the computations for the following distributions the slope b is always between m_1 and m_2, and the intercepts h_1 and h_2 are different in sign but are equal when $\alpha = \beta$.

Binomial distribution. This is the distribution to assume when each observation is recorded merely as insects present or absent (regardless of number) or damage present or absent, and the result is acceptance or rejection of a hypothesis. Every sampling unit in a lot should have the same chance of insects occurring on it. A plan would be based on this distribution, for example, if it were to be used to determine whether or not an infested area needed control. The limits for distinguishing "needing control" from "not needing control" would be stated as hypotheses in percentage terms—20 percent or less of the trees infested, no spray; 30 percent or more infested, spray. The application of sequential sampling to a problem of insect parasitism, based on the binomial case, has been discussed by Oakland (1951).

Table 1. Sequential table for sampling spruce budworm larval populations (4th-6th instars) on 15-inch balsam fir twigs[1]

(90 percent confidence level)

Number of twigs examined (1)	Cumulative number of budworms			
	Light (2)	Medium (3)	Medium (4)	Heavy (5)
1	----	----	----	29
2	3	----	----	39
3	8	----	----	50
4	12	22	23	60
5	16	26	33	71
6	20	31	44	81
7	25	35	54	92
8	29	39	65	102
9	33	43	75	112
10	38	48	85	123
11	42	52	96	133
12	46	56	106	144
13	50	60	117	154
14	55	65	127	164
15	59	69	138	175
16	63	73	148	185
17	67	77	158	196
18	72	82	169	206
19	76	86	179	217
20	80	90	190	227
21	84	94	200	237
22	89	99	210	248
23	93	103	221	258
24	97	107	231	269
25	101	111	242	279

CONTINUE SAMPLING (Light) *CONTINUE SAMPLING* (Medium (4))

[1]This table is used as follows: Sampling is continued only so long as the cumulative total count of budworms is between the listed values for LIGHT and MEDIUM (columns 2 and 3) or between those of MEDIUM and HEAVY (columns 4 and 5), or where a dash is shown. For example, if counts of 2, 3, 5, 4, and 1 budworms on successive twigs occurred, sampling would cease after the last (the 5th) twig because on that twig the count (15) fell below the limit value for LIGHT, and the sample would be so labelled. Similarly, when distinguishing between a MEDIUM and HEAVY population (columns 4 and 5), sampling is continued until the cumulative count of budworms for any given number of twigs is equal to or less than the count listed MEDIUM (column 4) or equal to or higher than that listed under HEAVY (column 5). A MEDIUM population is determined when the cumulative budworm count for any number of twigs (that is, 4 or more) is equal to or higher than the count listed for MEDIUM (column 3) and equal to or lower than that listed for MEDIUM (column 4). As indicated, it is possible to identify a LIGHT population after examining just 2 twigs, a MEDIUM population after 4 twigs, while a count of 29 or more budworms on the first twig would immediately specify a HEAVY population.

The equations for the decision lines are:

$$d_1 = bn - h_1 \text{ (lower line)}$$
$$d_2 = bn + h_2 \text{ (upper line)}$$

where d stands for the number of sampling units with insects present or trees with damage evident; n, the number of units examined; h_1 and h_2, the intercepts; and b, the slope of the lines.

The slope and intercepts are calculated by the following formulas (SRG, 1946):

$$b = \frac{\log \left(\frac{1-m_1}{1-m_2}\right)}{\log \frac{m_2}{m_1}\left(\frac{1-m_1}{1-m_2}\right)}$$

$$h_1 = \frac{\log \left(\frac{1-\alpha}{\beta}\right)}{\log \frac{m_2}{m_1}\left(\frac{1-m_1}{1-m_2}\right)}$$

$$h_2 = \frac{\log \left(\frac{1-\beta}{\alpha}\right)}{\log \frac{m_2}{m_1}\left(\frac{1-m_1}{1-m_2}\right)}$$

Negative binomial distribution. Bliss and Fisher (1953) found this distribution applicable to a wide range of biological data involving counts of plants or animals in units of space or time. Most forest-insect-survey data in the form of counts per sampling unit will follow this distribution. It is a type of "contagious" distribution, where the presence of one insect on a unit increases the chance of others occurring on that unit. This commonly results from larvae hatching from eggs laid in masses, or from gregarious feeding habits, although other factors may be responsible also.

In a negative binomial series the variance varies with the mean, but disproportionately so. This characteristic of the variance being significantly larger than the mean has been called "over dispersion" (Bliss and Fisher, 1953). The distribution is described by two parameters, the mean m and an exponent k. As the variance approaches the mean (and k approaches infinity) or as the population level decreases, the negative binomial will tend toward the Poisson distribution. Populations at low density may, in fact, fit the Poisson series more closely.

The k is theoretically independent of the mean, so that if a sequential plan is to be applied to a number of localities or over a wide area comprising different population levels, a pooled estimate of k should be obtained. Methods of estimating a common k for different sets of counts of an insect have been described by Anscombe (1949) and very recently by Bliss and Owen.[2]

The occurrence of both larvae and egg masses of the spruce budworm on 15-inch-twig sampling units from balsam fir trees agrees well with the negative binomial, and the sequential plan for sampling budworm larval populations that it described later in this paper was devised on that basis. Morris (1954) has developed sequential plans, based on the negative binomial case, for sampling spruce budworm egg-mass populations in New Brunswick on whole-branch sampling units. Oakland (1950) has described an application of sequential sampling to the inspection of whitefish for tapeworm cysts, the distribution of which also follows the negative binomial.

The decision line equations for this series are:

$$d_1 = bn + h_1 \text{ (lower line)}$$
$$d_2 = bn + h_2 \text{ (upper line)}$$

where d is the cumulative number of insects, n is the number of sampling units examined, b is the slope of the lines, and h_1 and h_2 are intercepts. The slope and in-

[2]Bliss, C. I., and A. R. G. Owen, 1954. Estimating k for a series of negative binomial distributions. (Unpub. manuscript; paper presented at meeting of Biometric Society, Gainesville, Fla.)

tercepts are calculated as follows (Oakland, 1950):

$$b = k \frac{\log \frac{q_2}{q_1}}{\log \frac{p_2 q_1}{p_1 q_2}}$$

$$h_1 = \frac{\log \frac{\beta}{1-a}}{\log \frac{p_2 q_1}{p_1 q_2}}$$

$$h_2 = \frac{\log \frac{1-\beta}{a}}{\log \frac{p_2 q_1}{p_1 q_2}}$$

where $p_1 = \frac{m_1}{k}$ and $q_1 = 1 + p_1$

$$p_2 = \frac{m_2}{k} \text{ and } q_2 = 1 + p_2$$

Poisson distribution. Insect counts at low population densities will often follow this distribution. The counts in this series, unlike those in the negative binomial and other contagious distributions, are distributed independently and at random among the sampling units. There should be no tendency to group or cluster on the same units, nor should the presence of one insect prevent the occurrence of others on that unit. Stated differently, the units in every sample lot must be equally subject to attack, that is, must have the same chance of containing insects. The Poisson is described by just one parameter, the mean. The variance is equal to the mean or close to it at all population levels.

The equations for the decision lines are:

$$d_1 = bn - h_1 \text{ (lower line)}$$
$$d_2 = bn + h_2 \text{ (upper line)}$$

where d is the cumulative number of insects, n is the number of sampling units examined, b is the slope, and h_1 and h_2 are the intercepts. The slope and intercepts are given by the following formulas[3] (SRG):

$$b = \frac{m_2 - m_1}{\log_e m_2 - \log_e m_1}$$

$$h_1 = \frac{\log_e \frac{1-a}{\beta}}{\log_e m_2 - \log_e m_1}$$

$$h_2 = \frac{\log_e \frac{1-\beta}{a}}{\log_e m_2 - \log_e m_1}$$

Normal distribution. This distribution, common or generally assumed in most experimental work, is probably the least frequent, however, in forest-insect sampling. With normally distributed populations the presence or absence of an insect on a sampling unit is in no way related to the presence or absence of others. The variance and mean, moreover, are also independent. Stark (1952) developed a sequential plan for sampling populations of the lodgepole needle miner based on a normal distribution of the insect on the sampling units used.

The decision line equations for this distribution are:

$$d_1 = bn - h_1 \text{ (lower line)}$$
$$d_2 = bn + h_2 \text{ (upper line)}$$

where d is the cumulative number of insects, n is the number of units examined, b is the slope, and h_1 and h_2 are the intercepts. The formulas for the slope and intercepts (Stark, 1952) are:

$$b = \frac{m_1 + m_2}{2}$$

$$h_1 = \frac{s^2 \left(\log_e \frac{1-a}{\beta} \right)}{m_2 - m_1}$$

$$h_2 = \frac{s^2 \left(\log_e \frac{1-\beta}{a} \right)}{m_2 - m_1}$$

[3]Logarithms denoted $\log_e$ are natural logarithms to the base 2.71828 and are 2.30259 times the corresponding common logarithms to the base 10.

where s^2 is the estimated variance of the population. This can be obtained from the preliminary samples taken to determine the distribution of the data.

Application to Spruce Budworm

The standard survey procedure for sampling larvae and egg-mass populations of the spruce budworm in the Northeastern States has been to examine five 15-inch twigs from each of five balsam fir trees at every collection point. As with probability sampling generally, the sampling points (collection points) and the sample trees at these points must be selected without personal bias, preferably by random selection. The 25 twigs are cut by pole-pruner from branch terminals at approximately mid-crown height. As the pole-pruners used by the survey crews can be extended only about 25 feet, samples taken from large trees are generally from the lower portion of the crown. On small trees the twig samples tend to be from the upper crown. The extremes in tree size are avoided, however, so for practical purposes the mid-crown level is considered the sampling universe for the survey collections.

In 1953 sequential plans were devised for sampling both larvae (4th to 6th instars) and egg masses, and each plan was tested for efficiency and reliability against the standard method.[4] With an upper limit of 25 twigs, the sequential method showed a 40-percent saving in twig-examination time for both larvae and egg masses, with no loss of reliability in correctly identifying the degree of infestation for each. No discrepancies between the two methods occurred over the 50 points sampled for larvae. In the egg-mass sampling just 2 out of 71 points were mislabeled, and both of these were between medium and heavy and could have been called either way.

[4]Waters, W. E. 1953. A study of the application of sequential sampling to spruce budworm populations. U.S. Dept. Agr. Forest Insect Lab. Ann. Rpt. 1953: p. 14. 18 pp. (Unpub.)

Based on new data obtained in 1953, revised sequential plans have been developed for the larvae and egg-mass surveys. The plan for distinguishing light, medium, and heavy populations of spruce budworm larvae (4th to 6th instars) is outlined below.

Light and Medium Populations

Class limits:

Light—3 larvae or less per 15-inch twig.
Medium—6 larvae or more per 15-inch twig.

Confidence levels:

1. Risk of calling a light infestation medium, $\alpha = 0.10$
2. Risk of calling a medium infestation light, $\beta = 0.10$

Pertinent values:

$m_1 = 3$	$m_2 = 6$
$p_1 = 0.415$	$p_2 = 0.830$
$q_1 = 1.415$	$q_2 = 1.830$
$k = 7.228$[5]	$k = 7.228$[5]

[5]Common k derived by new method of Bliss and Owen. Grateful acknowledgment is made to C. I. Bliss for the computation of this k, for suggestions concerning the negative binomial series, and for permission to describe briefly the procedure for obtaining a provisional k (suitable for survey sequential plans) by this method, as yet unpublished. The steps are as follows:

1. Compute the variance and mean of a set of representative samples (the 25-twig samples in this case).
2. Tabulate values of $s^2 - \bar{y}$ and $\bar{y}^2 - \frac{s^2}{n}$, where s^2 is the variance, $\bar{y}$ the mean, and n the number of units in the sample.
3. Plot above values on graph paper with $s^2 - \bar{y}$ on the vertical axis and $\bar{y}^2 - \frac{s^2}{n}$ on the horizontal axis.
4. If a few values are very discrepant they may be omitted. Calculate the mean values of $s^2 - \bar{y}$ and $\bar{y}^2 - \frac{s^2}{n}$, designated $\bar{y}'$ and $\bar{x}'$, respectively.
5. Draw a line from the 0 origin through the intersect of $\bar{y}'$, $\bar{x}'$.
6. Comp. $k = \frac{1}{\text{slope}}$, where the slope $= \frac{\bar{y}'}{\bar{x}'}$.

$$\text{The slope, } b = k \frac{\log \frac{q_2}{q_1}}{\log \frac{p_2 q_1}{p_1 q_2}} = 7.228 \frac{\log \frac{1.830}{1.415}}{\log \frac{(.830)(1.415)}{(.415)(1.830)}} = 4.257$$

and the intercepts,

$$h_1 = \frac{\log \frac{\beta}{1-\alpha}}{\log \frac{p_2 q_1}{p_1 q_2}} = \frac{\log \frac{.10}{1-.10}}{\log \frac{(.830)(1.415)}{(.415)(1.830)}} = -5.036$$

$$\text{and } h_2 = \frac{\log \frac{1-\beta}{\alpha}}{\log \frac{p_2 q_1}{p_1 q_2}} = \frac{\log \frac{1-.10}{.10}}{\log \frac{(.830)(1.415)}{(.415)(1.830)}} = 5.036$$

Decision lines:

The population is light if $d_1 \leq 4.257\,n - 5.036$[6]

The population is medium if $d_2 \geq 4.257\,n + 5.036$[6]

Medium and Heavy Populations

Class limits:

Medium—9 larvae or less per 15-inch twig.

Heavy—12 larvae or more per 15-inch twig.

Confidence levels: α and $\beta = 0.10$

Pertinent values:

$m_1 = 9$	$m_2 = 12$
$p_1 = 1.245$	$p_2 = 1.660$
$q_1 = 2.245$	$q_2 = 2.660$
$k = 7.228$	$k = 7.228$

The slope, $b =$

$$7.228 \frac{\log \frac{2.660}{2.245}}{\log \frac{(1.660)(2.245)}{(1.245)(2.660)}} = 10.416$$

and the intercepts,

$$h_1 = \frac{\log \frac{.10}{1-.10}}{\log \frac{(1.660)(2.245)}{(1.245)(2.660)}} = -18.656$$

$$h_2 = \frac{\log \frac{1-.10}{.10}}{\log \frac{(1.660)(2.245)}{(1.245)(2.660)}} = 18.656$$

Decision lines:

The population is medium if $d_1 \leq 10.416n - 18.656$

The population is heavy if $d_2 \geq 10.416n + 18.656$

The revised sequential plan applied to the 1953 survey data would have effected a 70-percent saving in time spent examining twigs for larvae with just 2 out of the 50 collection points mislabeled. Both of these incorrect calls would have been in the range between medium and heavy and could reasonably have been called either way. The plan is shown in graphic form in Figure 3 and in tabular form in Table 1.

Summary

Sequential analysis, a technique first developed in 1943 to expedite sampling in war research studies, is proving applicable to a wide range of biological data, including forest insect surveys. General formulas for devising sequential plans are given for the four mathematical distributions most commonly fitting forest insect survey data: binomial, negative binomial, Poisson, and normal. An application of this new

[6]The symbol $\leq$ reads "is equal to or less than"; the symbol $\geq$ reads "is equal to or more than."

Table 2. Computed values for the Operating Characteristic (OC) and Average Sample Number (ASN) curves of the sequential plan for spruce budworm larvae

Dummy variable	Light vs. medium populations				Medium vs. heavy populations			
x	p	m	L(m)	E(n)	p	m	L(m)	E(n)
∞	0	0	1.00	1.18	0	0	1.00	1.79
1	0.42	3.00	.90	3.21	1.25	9.00	.90	10.54
1/2	.50	3.61	.75	3.89	1.33	9.63	.75	11.87
0	.59	4.26	.50	5.96	1.44	10.42	.50	33.41
—1/2	.71	5.10	.25	2.99	1.54	11.11	.25	13.44
—1	.83	6.00	.10	2.31	1.66	12.00	.10	9.42
—3/2	.98	7.08	.04	1.64	1.78	12.87	.04	7.01
—∞	∞	∞	0	0	∞	∞	0	0

technique for determining spruce budworm larval populations is described. The computational procedures are outlined and the sequential plan is presented in graphic and tabular form. Operating Characteristic curves and Average Sample Number curves for this plan are also shown.

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Appendix

Formulas for Computing the Operating Characteristic Curve and the Average Sample Number Curve

Binomial Distribution

OC curve

$$(1)\ p' = \frac{x^{s} - 1}{x - 1},\ Lp' = \frac{x^{h_1 + h_2} - x^{h_1}}{x^{h_1 + h_2} - 1}$$

$$(2)\qquad p'' = p'\,x^{1-s},\ Lp'' = \frac{Lp'}{x^{h_1}}$$

When various values are assigned to the dummy variable x in the equations above, formula 1 gives that portion of the curve for which p lies between 0 and b and formula 2 gives that portion of the curve for which p lies between b and 1. For plotting, $L(m)$ will be the computed values of Lp' and Lp'', and m will be the successive values of Kp' and Kp''. The quantity x should always be greater than 1.

If α and β are the same, a single formula for p which does not involve a dummy variable can be used:

$$(3)\quad p = \frac{\left(\frac{Lp}{1 - Lp}\right)^{\frac{b}{h}} - 1}{\left(\frac{Lp}{1 - Lp}\right)h - 1}$$

where $h = h_1 = h_2$

ASN curve

$$E(n) = \frac{Lm\,(h_1 + h_2) - h_2}{b - p}$$

Poisson Distribution

OC curve

$$(1)\ m' = \frac{b \log_e x}{x - 1},\ Lm' = \frac{x^{h_2} - 1}{x^{h_2} - x^{-h_1}}$$

$$(2)\quad m'' = m'x,\ LM'' = x^{-h_1}\,Lm'$$

Substitution of various values of x in the equations above gives successive points on the OC curve. In these equations also, x should always be greater than 1. The plotting values of $L(m)$ and m will be the computed values of Lm', Lm'' and m', m'', respectively.

When $\alpha = \beta$ (and $h_1 = h_2$) a single formula for m can be used:

$$(3)\qquad m = \frac{\frac{b}{h}\ \log_e \frac{L(m)}{1 - L(m)}}{\left(\frac{L(m)}{1 - L(m)}\right)^{\frac{1}{h}} - 1}$$

ASN curve

$$E(n) = \frac{L(m)\,(h_1 + h_2) - h_2}{b - m}$$

Normal Distribution

OC curve

$$(1)\quad K = \frac{2\,(b - m)}{S^2}$$

$$(2)\quad t_1 = h_1 K$$

$$(3)\quad t_2 = (h_1 + h_2)K$$

$$(4)\quad L(m) = \frac{e^{t_1} - 1}{e^{t_2} - 1}$$

The plotting values of $L(m)$, m are calculated by assigning various values of m in equation 1 and computing the corresponding $L(m)$'s from equation 4. The quantities e^{t_1} and e^{t_2} are computed by use of *Tables of Exponential Function* e^x, Federal Works Agency, Works Project Administration for the City of New York, National Bureau of Standards, 1939.

ASN curve

$$E(n) = \frac{L(m)\,(h_1 + h_2) - h_1}{m - b}$$

The Physical and Economic Foundation of Natural Resources.

I. Photosynthesis—Basic Features of the Process. 1952. 78 pp. II. The Physical Basis of Water Supply and Its Principal Uses. 1952. 93 pp. III. Groundwater Regions of the United States—Their Storage Facilities. 1952. 78 pp. IV. Subsurface Facilities of Water Management and Patterns of Supply—Type Area Studies. 1953. 206 pp. Compiled by and available from the Committee on Interior and Insular Affairs, U. S. House of Representatives, Washington, D. C.

REVIEW by G. Robinson Gregory
University of Michigan

SOME time prior to 1952 the House Committee on Interior and Insular Affairs requested Dr. J. R. Mahoney, Senior Specialist in Natural Resources of the Library of Congress, to "explore the possibility of securing the cooperation of various scientists in a preliminary appraisal of these resources . . ." The response elicited from various authorities, both within governmental agencies and on university faculties, is a testimony to the persuasive ability of Dr. Mahoney.

The reports are intended to establish the important features of some of the nation's basic natural resources, thereby aiding individuals in policy-making positions to reach sound decisions and establish logical policies. In addition, they are intended to highlight areas in which present knowledge is fragmentary.

The first of the series is a summary of the latest scientific information regarding the most fundamental of all plant processes. By no means a textbook on photosynthesis, this report constitutes a valuable summary to all who are interested in keeping abreast of scientific advances on the photosynthetic front.

The remaining three publications are devoted to developing certain specific aspects of the water resource problem. Volume two covers topics ranging from Evapotranspiration in the Hydrologic Cycle" to "Vapor Compression Distilling Plants." As one might expect from a collection of this type, the coverage is neither uniform nor complete. Yet the chosen topics are dealt with authoritatively, and are presented in reasonably clear and concise fashion.

The third volume is the work of Dr. Harold E. Thomas of the U. S. Geological Survey who will be recalled as the author of "The Conservation of Ground Water." The present paper provides "a description and discussion of ground-water occurrence and resources in the ten major ground-water regions of the United States." Because of its readability, this volume may be the most useful of all to the college teacher dealing with natural resource problems.

The final and longest report is "designed to show how water supplies can be more effectively controlled through the use of sub-surface geological formation." The ground water problems of eight sample areas in the west and south are analyzed in detail.

The final chapter to volume four warrants special comment. Prepared by William E. Hiatt of the Weather Bureau, it summarizes a project designed "to advance the methodology of extracting maximum interpretations from scarce data." For men forced to rely upon infrequent and incomplete observation of weather phenomena this chapter may provide powerful new analytical assistance.

As far as establishing "the physical and economic foundations of Natural Resources," the present volumes barely scratch the surface. The reports deal almost entirely with the physical aspects of resources, with little more than lip service rendered to the economic problems. Furthermore, water is the only resource singled out for major emphasis. If the committee should decide to continue along the path pioneered and can maintain the high standards set thereby, a significant contribution to the natural resource field will result.

Suggestions to Contributors

An article submitted for publication should be the best the writer is capable of producing, with all statements, tables, quotations, names and formulas verified before submission. The careful author will have his typescript reviewed by colleagues.

Articles should be typewritten, with 1½-inch margins, on one side only of white bond paper, size 8½ by 11 inches, or 8 by 10½ inches. Carbon copies are not acceptable. All copy should be double-spaced. Pages should be numbered consecutively, preferably in the upper right-hand corner. Only words intended to be set in italics should be underlined.

Material such as equations that exceed 42 spaces on the typewriter cannot be carried in a single line. Such material should either be set so that it can be broken into two or more lines, or should be presented in tabular form.

Tables

Each table should be typewritten on a separate sheet, given a title at the top, and should be numbered consecutively. Even if only one table is submitted, it should be designated Table 1.

Footnotes used in tables should be designated by numerals, never by asterisks or other typographical symbols. These footnotes should be typewritten as part of the table.

Illustrations and Figures

An illustration — whether a photograph, a line drawing, a map, or a graph — is designated as a figure. A caption should be submitted for each illustration, but the caption should be typewritten on a separate sheet.

All figures should be numbered consecutively. If only one is submitted it should be designated Fig. 1. On the margin or back of each illustration should be written lightly in soft pencil the number of the figure, the name of the author, and an abbreviated title.

Photographs should be sharp and clear, printed on glossy paper. They should not be smaller than 4 by 5 inches. Sizes 5 by 7 inches and 8 by 10 inches are preferable. Photographs should never be rolled or bent. Care should be taken in fastening photographs with paper clips which often make indentations that show up in reproduction.

Drawings, maps, charts, and graphs are reproduced as line engravings. They should be at least twice as large as they are to appear when reproduced, and should be drawn in india ink on heavy white paper, or tracing cloth.

Footnotes

To indicate a footnote, place a superior figure after the word that refers to the note. Consecutive numerals should be used, never asterisks. Separate the footnote from the text by running a line about one inch inward from the left margin of the type.

Use footnotes to give credit to unpublished material and communications. If only a few references to literature are made (less than one per 1000 words), complete literature citations may be given in footnotes rather than in a separate listing.

Literature Cited

In FOREST SCIENCE practice, references to literature citations are designated by the author's name and year of publication inserted in parentheses at the appropriate place in the text. If there are more than two authors, list only the senior acthor's name in the text with the abbreviation *et al.* Example: (Smith *et al.*, 1954). Only published references should be given in *Literature Cited*. Periodical abbreviations should follow *Guide to the use of Forestry Abstracts*, Commonwealth Forestry Bureau, Oxford, England, 1950.

Nomenclature and Terminology

When a species is first mentioned in a paper its common name may be immediately followed by its italicized scientific name in parentheses, but this latter name need not be repeated.

As the authority for the exact spelling of tree names, FOREST SCIENCE follows *Check List of Native and Naturalized Trees of the United States (including Alaska)*, Agriculture Handbook 41, Forest Service, U. S. Dept. Agric., Washington, D. C., 1953.

For the spelling of other plant names, contributors should follow *Standardized Plant Names*, 2d Edition, J. Horace McFarland Company, Harrisburg, Pa. 1942.

Technical usage in forestry and allied fields follows *Forest Terminology*, 2d Edition, Society of American Foresters, Washington 6, D. C. 1950.

There are many style manuals available for the guidance of writers. One of the best is the *Style Manual* of the U. S. Government Printing Office, Washington 25, D. C. 1953.

Webster's *New International Dictionary* is the accepted authority for general spelling.